Volume 14 SEPTEMBER, 1935 Number 9

THE BULLETIN

OF THE

AMERICAN CERAMIC SOCIETY

Photo Courtesy Frederick H. Rhead

The Fourth Annual Robineau Memorial Ceramic Exhibition will be held from October 15 to November 11, 1935, to honor the late Adelaide Alsop Robineau here shown working on her famous scarab vase on which she spent more than 1000 hours carving the decoration and glazing the piece.

In firing this piece, several large gaping cracks were formed. Mrs. Robineau filled these with ground porcelain; the vase was then reglazed and refired, and this time came out perfect.

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THE BULLETIN

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Volume 14 September, 1935 Number 9

PAPERS AND DISCUSSIONS

GEOLOGY AND CLAY RESEARCH*

By H. Ries†

Editor's Note: This paper was presented at the Annual Meeting, American Ceramic Society, Buffalo, N. Y., on the evening of February 19, 1935, as the third Edward Orton, Jr., Fellow Lecture.

I. Introduction

It is well known that mineral wealth has been an important factor in the development of nations because the mineral products of the earth's crust supply the raw material for many industries.

At no place is this better exhibited than in one of the largest commercial museums of the world, the Deutsches Museum of Munich, where the relationship is brought out in a most striking and convincing manner.

Beginning with the Hall of Geology, in which the various processes leading to the formation of rocks and mineral deposits are shown, one passes successively to the exhibits of the raw materials, the methods of extraction and purification and, finally, to the display of manufactured products.

The entire setting and arrangement can not fail to impress one with man's dependence on Mother Earth for many materials of value to civilization.

Incidentally, it also serves to suggest the rôle which the geologist may play in the discovery and evaluation of mineral deposits, whose raw materials the technologist converts into the finished product.

The geologist who is interested particularly in nonmetallic minerals must, in addition to concerning himself with the extent and richness of a deposit, have some familiarity with the possible uses of the material and the requirements for different purposes.

The reason for this should be obvious, since nonmetallic minerals can not always be concentrated or purified; it may be necessary, therefore, to utilize them as mined. This means that their market value and uses will be determined in part by the quantity and nature of impurities which they contain, as illustrated by a comparison of brick clay and ball clay.

There is no implication here that all nonmetals are incapable of purification, for this process is being practiced to some extent, and the washing of clay would represent a simple case.

I would not, however, throw all of the responsibility of judging raw minerals on the geologist, for I believe the technologist should have some conception of how the mineral deposits are formed and the variations which different genetic types are likely to show, since he is at times called upon to examine them, and geologic training then becomes an important and valuable asset.

The geologist and technologist should therefore coöperate with each other, and it is a pleasure to note that no one better appreciated the close relationship that should exist between these two groups than the late General Edward Orton, Jr.,

* Received February 27, 1935.

† Head of the Department of Geology, Cornell University, Ithaca, N. Y.

to whom this Society owes so much and as a memorial to whom this annual lecture is given.

Both the geologist and technologist are interested in research problems, the one primarily with the distribution, origin, and related irregularities of the deposits; the other, with the properties of the substance itself, particularly as they affect the processes of manufacture and quality of the finished product.

Research, however, requires money as well as time, and funds for it are not always forthcoming, unless the prospective donors can be persuaded that the results will be of practical value. This is especially true of geology, a fact which some comparisons will make clearer.

For instance, it is of the greatest importance to oil companies to obtain accurate information regarding the mode of occurrence of oil, the source rocks, and the cause and the amount of migration to enable them to prospect intelligently. Funds have, therefore, been liberally subscribed for the investigation of these problems.

Some years ago the copper-mining companies of the United States contributed a large sum for studying the process of secondary enrichment of copper ores, a question of vital import to this branch of the metal mining industry, because it was desirable to know what changes might take place in the richness of the ore as it was followed downward.

Equally interesting and important from the scientific standpoint would be a critical study of the mode of origin of different types of clay, their distributions, and relationships, but unless it can be shown that this research will help us to find more and better supplies of this valuable type of plastic material, funds will not be easy to obtain.

When, however, it comes to research on the finished product, methods of testing, and improvements in technology, all clearly promising results of practical value, financial aid will more probably be forthcoming.

But in spite of a lack of financial support, researches into the constitution of clay, its formation, etc., have been carried on over a period of years by a number of enthusiastic field and laboratory workers, and their labors have led to a much better understanding of this material.

You, as ceramists, naturally think chiefly of its uses for fired clay products, but there are others, such as the cement manufacturers, foundrymen, paper makers, oil producers and refiners, road engineers, agriculturists, and geologists, who take an interest in clay for different purposes. Some of these may be interested only in certain special properties of the raw material; others may be concerned with a variety of them. So while it is true that their interests are somewhat different, there is a common ground on which they should meet and profit by an exchange of views. As it is now, I venture to say that they do not always understand each other's problems as well as they might. One group may even reject the methods of study which another uses for testing the same property, or methods of testing, apparently rejected by one class, may be taken up and improved by another group.

In this address, I shall discuss the subject mainly from the point of view of the geologist and indicate what seem to be some of the interesting and unsolved research problems on clay.

Looking through the literature on clays covering a period of forty or fifty years, one can not help being impressed by the expansion of knowledge regarding this interesting group of materials. We are almost rid of the oft-printed phrase that all clay is a hydrated silicate of alumina (kaolinite) derived from feldspar.

Do not understand me as intimating that we have arrived at a definition of clay which suits everyone. The geologist, chemist, ceramist, and agriculturist are all likely to define it in different terms. If we try to include the features of mineral composition, particle size and shape, chemical composition, etc., we are likely to get a definition as long as some hypothetical questions in a legal trial. Mineral and chemical composition and particle shape are so variable as to be of doubtful value as a basis for defining clay.

Materials that any ceramist would call clay in a moist condition may show remarkable variation in mineral composition and particle shape. Bentonite, for example, is composed largely of platy particles, while other clays show few signs of scales (Fig. 1).

Particle size is no doubt a property of great importance, and plasticity is another, to which we might add hardening when fired.

II. Origin of Clay

Since it is probable that the original formations of the earth's crust were of igneous origin, then it is fair to assume that when water began to

accumulate on the earth's surface, the minerals of these rocks were attacked by this medium, decomposing at least some of them to claylike materials which were washed into the ancient oceans or lakes, where they were deposited as aluminous sediments.

Igneous rocks resemble fired clay products in being composed largely of silicates, but they may differ from them in texture and in being formed under different conditions.

The crystallization of magmas below the earth's surface takes place under great pressure. It goes on with extreme slowness, and the presence of water in the molten mass may exert an important influence on the texture and even on fusibility, conditions which are practically absent in the kiln.

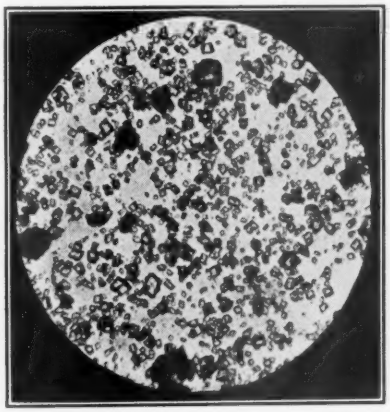

FIG. 1.—Clay composed chiefly of minute dolomite rhombs.

Surface cooling of igneous rock proceeds more rapidly, and the texture of the rock is correspondingly finer, or with very rapid cooling it may even be glassy, with few identifiable crystals. Where large crystals are present, they were no doubt formed before the magma reached the surface.

Because of the difference in physical conditions surrounding a cooling magma below the surface and a clay mixture in the kiln, the former may develop an abundance of identifiable crystal grains, while the latter shows few of them, except mullite. Clays or shales, fused by the burning of a coal bed, may show more minerals than those fired in the kiln. This may be due to the fact that fusion has been prolonged and the formations of the minerals have been assisted possibly by the presence of moisture.

III. Weathering Processes

We are prone to speak of the weathering of rocks and their change to clay as a simple matter, forgetting how complex are all the geologic processes involved in the origin of this material, including as they do various phases of weathering, sedimentation, the formation of new minerals, the phenomenon of base exchange, etc.

All these processes are of interest to the geologist while some of them have their counterpart in the clayworking industry.

Weathering processes are in most cases exceedingly slow, and we still have much to learn regarding them. They are affected by a number of factors such as texture, porosity, permeability, and mineral composition of the parent rock.

FIG. 2.—Porphyritic weathered granite.

Fine-grained rocks, if permeable to water, may be more readily attacked than coarse-grained ones, where the larger grains expose less surface area to the action of solutions. As a result, in porphyritic granites (Fig. 2), the large feldspars often stand out in relief as the fine-grained silicates weather away. Massive glassy lavas seem to be particularly resistant to weathering.

Basic minerals succumb more readily than acid ones.

Selecting a few common ones, we find that their order of decreasing resistance is quartz, muscovite, biotite, orthoclase, plagioclase, epidote, and hornblende.[1]

[1] H. O. Buckman, "Chemical and Physical Processes Involved in Formation of Residual Clay," *Trans. Amer. Ceram. Soc.*, **13**, 336 (1911).

While it is generally agreed among geologists that both physical and chemical processes may be operative in the weathering of rocks and the same might apply to fired clay products (though often to a lesser degree), there may be a difference of opinion as to which of the two classes of processes is the more important.

(1) Mechanical Weathering

Much emphasis has been placed by geologists on the insolation hypothesis which assumes that rocks finally rupture after years of exposure to alternating stresses of differential expansion and contraction caused by daily changes in temperature at the rock surface.

This is supposed to cause a splitting and crumbling which is most effective in firm dense rocks; but Blackwelder[2] has pointed out its improbability since rocks are rarely exposed to a daily range of temperature of more than 50°C, and laboratory experiments indicate that practically all rocks will resist, without rupture, sudden changes of 200°C. No natural glasses were tested, and it is possible that these might be more sensitive. We may ask, however, whether temperature changes continued day in and day out and year after year will not in the end cause a cracking of the rock.

Frost action is often referred to as an agent of disintegration and while it may be an effective one, destructive both to rocks and fired clay products, it can only operate where water can permeate the material, saturate it more or less effectively, and not drain off easily. Frost is, however, mentioned probably more than any other possible agent of disintegration, and I think one may well question whether this view is correct.

Rocks disintegrate in frostless regions and even in frosty ones, where the failure can be traced directly to crystallizing salts absorbed, in many cases, from the soil.

While this is one obvious effect of soluble salts, there are others which are less apparent, and one may raise the point whether this is not a more widespread cause of disintegration than is generally conceded.

Atmospheric gases, carrying CO_2, may carbonate the lime in rocks, mortar, or clay products, and the carbonate may in turn be converted into $CaSO_4$ by SO_2 from the atmosphere, which compound, being slightly soluble, may be brought to or near the surface and crystallize, thus prying off pieces of the material. This action is not an uncommon one in some rocks and might affect clay products as well.

Salts from sea water, not necessarily sulfates, may be blown with spray onto the surface of porous materials, where they are absorbed and create trouble by crystallization (Fig. 4).

FIG. 3 (upper).—A sandstone with carbonate cement converted into sulfate by atmospheric gases; the sulfate has crystallized below the surface.

FIG. 4 (lower).—Disintegration of brick along sea coast, due probably to salt spray.

Not to be overlooked is the fact that some compounds show a change in volume in passing from a stable to a metastable condition and that this transformation, which may be reversible, can take place within a range of temperature repre-

[2] E. Blackwelder, "The Insolation Hypothesis of Rock Weathering," *Amer. Jour. Sci.*, 5th Ser., **24**, 98 (1933).

sented by the warmth of sunshine and the coolness of night. This is a feature which, though it may appear insignificant, is worth considering, for it often is the slow continued action of an apparently small force which may cause failure in the end.

In dealing with sedimentary rocks or even deposits of consolidated volcanic ash, softening of the bonding material by the action of water alone may cause weakening of the structure, which in the case of some building stones has been found to result in decreasing strength. This would hardly apply to clay products unless they were very lightly fired.

(2) Chemical Weathering

The chemical processes of weathering are most complex and not thoroughly understood.

Simple solution may be a dominant factor in certain rocks, like limestone and gypsum or calcareous shales, removing the carbonates or sulfates and leaving behind an insoluble residue, often of clayey nature. Where silicate minerals are involved, however, the processes are much more complicated.

Water may carry H and OH ions, O, CO_2, organic acids, and dissolved salts, capable of setting up a whole series of reactions, such as hydration, base exchange, etc.

Hydration is a process which may operate wherever water comes in contact with silicates, and since it involves increase of volume it must have a disintegrating effect. It seems not improbable that the same process may operate very slowly in fired clayware which absorbs moisture.

It is possible that wetting and drying may be more effective than permanently wet conditions. An excellent example of this is seen in parts of California, where the climate may be regarded as far from humid and rain falls chiefly during the winter, so that the rocks get fairly well dried out in summer and yet in places they are more or less decayed to an appreciable depth.

If the composition of a fresh igneous rock is compared with that of its decomposition product, one finds in general that chemical weathering appears to have removed alkalis, alkaline earths, and in some cases silica, while iron and alumina are left behind.

The change, however, must be a complicated one, and does not always show the trend indicated above. In lateritic weathering, silica would be removed, while in podsolic weathering, a type common to temperate regions, the alumina and iron oxide tend to be carried away instead of the silica.

One may further question whether the analysis of the fresh rock and the residual clay really tell the entire story of what has happened.

Many of the bases set free may be held in the clay by base exchange, or adsorption, so that an analysis of it does not really show what has been liberated in weathering. Some of these bases may still later be replaced by hydrogen, forming acid clay.

Lime set free by the weathering of a limestone may be absorbed by the residual clay but is easily displaced by the hydrogen ion. Theoretically then, a residual clay from limestone might, after its formation, contain appreciable lime.

Since silica may be removed by weathering, it is suggested that clays such as the diaspore clays of Missouri, have been derived from flint clays by the removal of silica, and one may ask whether laterites and bauxites are not an end stage of the same process. Certain geological features of bauxite point in this direction because many of the deposits are found underlying ancient land surfaces where they resulted from prolonged weathering. Furthermore, in the Arkansas bauxite district, we find the bauxite grading downward into kaolin, and this, in turn, to syenite.

IV. Clays of Hydrothermal Origin

Although we usually think of residual clays as being formed by weathering processes, we must concede that at least some of the so-called clay minerals, of which I shall have more to say later, may be formed by rising magmatic solutions which alter the silicates.

Indeed, the idea has been expanded to suggest that some kaolin deposits have originated in this manner. Every case of this type, however, should be critically studied before drawing a final conclusion. There are a few kaolin deposits whose origin by subaerial weathering has been disputed, and they rise up to plague us from time to time, because their relationships are such as to prevent a definite opinion regarding their genesis.

From a practical standpoint, it might be very

comforting to believe that a kaolin deposit is of hydrothermal origin, formed by rising igneous waters acting on feldspars or similar rock minerals, because such a deposit might extend to a much greater depth than one formed by simple weathering.

The hydrothermal theory was most actively argued some years ago by H. Rösler, who published a lengthy article to prove that all kaolins were formed by igneous waters, but his premises, in many cases, were wrong and had he examined some of the deposits carefully, he should have been able to see that they were the result of weathering.

The theory of hydrothermal origin should, however, not be completely rejected, for it may apply in some cases.

FIG. 5.—Veins and patches of kaolin in quartzite at St. Remi, Quebec.

One of the outstanding examples is that of Cornwall, England, where the deposits have been worked to a depth of 240 to 250 feet and are not yet bottomed. Some of the English geologists still believe that they are of hydrothermal origin, their depth and the fact that in some cases the kaolin is "overlain" by granite being among their chief arguments.

In North America, two cases have been suggested. The first of these is that peculiar deposit at St. Remi in Quebec, where the kaolin occurs in feldspathic quartzite.[3] The fact that the kaolin occupies certain fracture zones in the quartzite, and that there has been no kaolinization of the adjoining gneiss, has lead some to suggest that it is a product of hydrothermal alteration.

The second case is a group of kaolins near Spokane, Washington,[4] which form truly remarkable stringers of kaolinite, sericite, and quartz in sandstone. Since they contain not a trace of feldspar, it is thought they can not be the result of weathering. Moreover, the associated granite does not show kaolinization. A penumatolytic origin is assigned to them.

Here again, the clay mineral has been identified as kaolinite and if it is, either the theory of origin is wrong or else the present views regarding the usual conditions of formation of kaolinite must be modified.

V. Replacement by Kaolinite

The occasional deposition of kaolin minerals from solutions, especially in a quartz rock, leads us to the conclusion that they must have been formed by replacement.

What compound of alumina is carried in solution has not been determined; it may be sulfate, but the evidence seems pretty clear that alumina-bearing solutions, either hot or cold, can attack quartz and form kaolinite or perhaps other hydrous aluminum silicates.

I first became impressed with the possibility of this process when studying the curious deposits of Huron County, Indiana. There the white clay, called indianaite, but which is not representative of a single mineral species, occurs in the pebbly (Mansfield) sandstone in such a manner as to leave no doubt that it is the result of replacement. It surrounds isolated blocks of the sandstone which preserve their original orientation in the deposit, and veins of clay also traverse the sandstone and even the pebbles.

It is suggested that the alumina was derived from the underlying pyritiferous shales and that circulating meteoric waters carried it as aluminum sulfate into the sandstone, where it replaced the quartz pebbles. Logan has expressed the view that bacteria played a rôle, but this assumption seems hardly necessary.

[3] M. E. Wilson, "Geology and Mineral Deposits of a Part of Amherst Township, Quebec, Can.," *Geol. Surv., Mem.*, No. 113 (1919).

[4] G. A. Goodspeed and A. A. Weymouth, "Mineral Constituents and Origin of a Certain Kaolin Deposit near Spokane, Wash.," *Jour. Amer. Ceram. Soc.*, **11** [9] 687–95 (1928).

Ross has given corroborative evidence of kaolinite replacement by showing that deep embayments in quartz sand grains from Louisville, Mississippi, and Camden, Alabama[5] (Fig. 8) are filled with kaolinite. He points out, however, that the arkosic sands of the Gulf coastal region contain little pyrite, so there is lacking a source of sulfuric acid to form aluminum sulfate, and the mode of transportation of the alumina is not clear. The outstanding feature is that the kaolinite has replaced quartz.

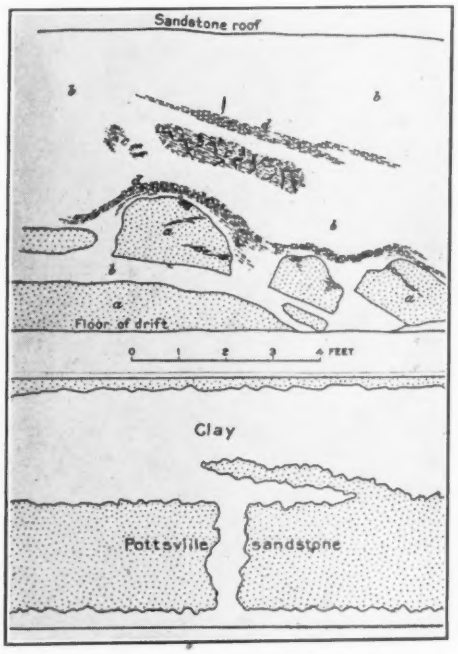

FIG. 6 (upper).—Sections showing Mansfield sandstone surrounded and impregnated by white clay (after H. Ries, *U. S. Geol. Surv. Bull.*, No. 708); *a*, sandstone; *b*, milk-white clay; *c*, waxy clay; *d*, clay that shows banded structure.

FIG. 7 (lower).—White indianaite (clay) overlying sandstone, vein of indianaite crossing the sandstone and in fin of sandstone extending upward into the indianaite in the Gardner mine, near Huron, Ind.

VI. The Clay Minerals

It may be well at this point to refer briefly to the origin of the clay minerals, *viz.*, those hydrous aluminum silicates which occur as a predominating constituent of many clays, their isolation and identification having been made possible only in recent years by improvements in determinative mineralogy and petrography.

[5] C. S. Ross and P. F. Kerr, "The Kaolin Minerals," *U. S. Geol. Surv. Prof. Paper*, No. 165-E, p. 174, 1931.

Much credit is due to C. S. Ross and P. F. Kerr for the results obtained, and their investigations have shown us that many of the fine particles in clays represent identifiable minerals.

Special attention has been given thus far to kaolinite, dickite, nacrite, halloysite, and allophane in the white clays and, in addition, montmorillonite, beidellite, and nontronite for the more impure ones.

Aside from their identification, we are interested in the conditions under which they are formed, while a further problem would be a study of their influence on the various properties of clay, both in its raw and fired condition.

We are most apt to think of the clay minerals as products of weathering, but wider observation has shown us that some of them may originate by hydrothermal action or even under marine environment.

Kaolinite is commonly the result of complete weathering of aluminous silicates, the conditions being possibly analogous to lateritization. We do not ordinarily regard it as a mineral that may also be formed at depth by rising hot waters, but its occasional occurrence in ore veins below the zone of weathering indicates this.

Still unsolved is the question of whether kaolinite always forms directly as such or whether it may not result from a combination of colloidal silica and colloidal alumina, which might account for the occurrence of authigenic kaolinite (Fig. 9) in sediments, similar to the origin of chamosite in sedimentary iron ores. There is no doubt that the constituents of kaolinite may be carried by meteoric waters, for its presence in the cracks of concretions points that way.

Dickite, on the other hand, appears to be usually of hydrothermal origin, but its occurrence in some geodes indicates that meteoric waters are capable of depositing it, and its more recent discovery in fractures in sandstone (Fig. 10) associated with a Pennsylvania coal suggests a similar source.

Halloysite, so abundantly associated with kaolinite, seems to be a crystalline product of surface water activity and, as far as we know, the same is true of the amorphous allophane, which Ross and Kerr regard as a "mutual solution of alumina, silica, and water." It is commonly found with halloysite as in the indianaite of Indiana, where it has a glassy appearance.

The theory has been advanced that allophane

may crystallize to form halloysite, and that the latter may in turn recrystallize to kaolinite.

The montmorillonite-beidellite group is more enigmatic than the kaolin group, and the fact that the members contain certain bases, such as lime and magnesia, makes them more susceptible to base exchange than the kaolin minerals.

The exact conditions of their origin still remain to be explained. We know that montmorillonite forms from the glassy particles of volcanic ash, sometimes under marine conditions, occasionally by weathering, and, in one case at least, by hydrothermal waters. This might suggest that composition of the water causing the change was important rather than the temperature.

Beidellite develops generally from the weathering of silicates, such as feldspar, hornblende, and epidote, or even volcanic ash, but in the graphite deposits of California it has been found to be of hydrothermal origin.

The case becomes more complex when we discover that beidellite, montmorillonite, and even kaolinite may, at different times, form from volcanic ash.

Similarly, different genetic conditions may be exhibited by diaspore and gibbsite.

One hydrous aluminum silicate, pyrophyllite, not included with the clay minerals, is interesting in that it is a hydrothermal mineral which has replaced bodies of volcanic ash and breccia (Fig. 11).

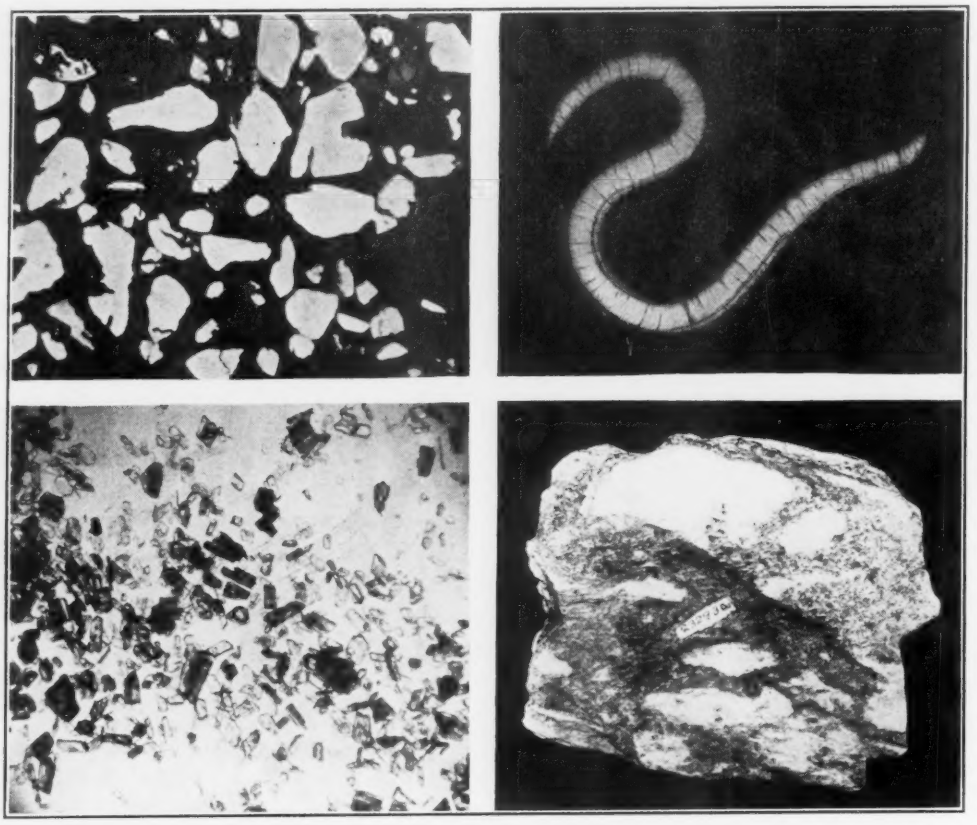

FIG. 8 (upper left).—Quartz grains replaced by kaolinite (after Ross and Kerr, *U. S. Geol. Surv. Prof. Paper*, No. 165).
FIG. 9 (upper right).—Grain of kaolinite formed in sand (after Ross and Kerr, *ibid.*).
FIG. 10 (lower left).—Crystals of dickite from Pennsylvania.
FIG. 11 (lower right).—Volcanic breccia replaced in part by pyrophyllite.

VII. Sedimentary Clays

Abundant as are the problems of the residual clays, those of the sedimentary ones are even more numerous, particularly in the case of the more extensive deposits.

We have to deal with such questions as the source of the sediments and whether they were deposited in fresh or salt water or perhaps even on the land.

There is also the possibility that the clays have undergone chemical changes during deposition or may have resulted from the alteration of nonargillaceous sediments.

VIII. Source of Sediments

It is commonly assumed that the sedimentary clays, such as those deposited in estuaries or the sea, were derived from regions drained by rivers discharging into such bodies of water and that they came from the erosion of areas of residual clay or preëxisting sedimentary formations. The details of the process are, however, not always easily worked out.

A rather simple case would be that of the Ione clays of the California Tertiary, which lie along

FIG. 12.—White sedimentary clay, South Carolina.

the eastern side of the Great Valley.[6] They appear to be lateritic products of weathering washed from the Sierra Nevada highlands and deposited as great deltas in the Tertiary sea that occupied the depression to the westward.

In strong contrast to the preceding is the belt of Cretaceous and Tertiary clays which, beginning at New Jersey, extends southward along the Atlantic and Gulf Coastal plains and then swings northward to southern Illinois.

It contains some of the most important sedimentary clay deposits of the United States; these show not only striking horizontal variations but also vertical ones.

The Raritan formation of the Cretaceous carries an abundance of refractory clays in New Jersey, while in Maryland it is mostly sand. Its probable equivalent in age carries white clays in Mississippi and Alabama, but between the two areas mentioned the Raritan is absent either because there was no deposition or, if deposited, it has been eroded.

We are undoubtedly confronted with a difficult problem in sedimentation.

If one assumes that all the sediments of this great clay belt are of marine or estuarine origin, it might seem reasonable to expect that rivers draining different areas underlain by residual clays derived from different formations would yield clay sediments which were dissimilar and that during the process of erosion and deposition sand and clay would be separated from each other.

But, admitting that these residual clays were impure, how can we derive from them deposits of fire clay low in impurities or, more particularly, large deposits of white clays like those of Georgia, South Carolina (Fig. 12), or Alabama.

To explain some of these, the geologist has appealed to leaching by humic acids which came from organic deposits overlying the residual material, so that it was purified before removal.[7] The idea is not an unreasonable one, since it is known that impurities may be removed by this process.

An alternate explanation which has been applied to the white Alabama clays is that they represent flood plain deposits purified by leaching,[8] but this explanation must of course be considered speculative in the absence of additional proof, although the origin of bauxite deposits by leaching accompanying weathering is pointed to as evidence of such possible action.

Obviously, the leachability of a clay depends on its permeability and must at times proceed with great slowness; indeed, it can take place only in deposits so situated that water can drain through them. The possibility of such a leaching process is indicated by the profiles of some soils, in which we find a series of zones from the surface downward, these being differentiated by the leaching and oxidation which they have undergone.

Allen[9] has shown that the underclays of Illinois coals represent ancient leached soils.

[6] V. T. Allen, "The Ione Formation of California," *Univ. Calif. Pub. Bull.* [Dept. Geol. Sci.], **18** [14] 347–448 (1929).

[7] F. R. Neumann, "Origin of the Cretaceous White Clays of South Carolina," *Econ. Geol.*, **22**, 374 (1927).

[8] G. I. Adams, "Origin of the White Clays of Tuscaloosa Age (Upper Cretaceous) in Alabama, Georgia, and South Carolina," *ibid.*, **25**, 621 (1930).

[9] V. T. Allen, "Petrographic and Mineralogical Study of Underclays of Illinois Coals," *Jour. Amer. Ceram. Soc.*, **15** [10] 564 (1932).

Ross[10] has also suggested that some of the western Kentucky fire clays have been leached. He points out that the upper parts of certain clay beds show a difference in chemical composition from the lower portion, indicating removal of material by solution.

It must be admitted that while the alteration of a sedimentary clay deposit by percolating water is possible, nevertheless, on account of the low permeability already referred to, the change would require a very long time. The subject is, however, worthy of further investigation but it requires careful chemical and petrographic work.

IX. Heavy Minerals

Since certain heavy minerals are sometimes found to be characteristic of certain sedimentary formations, these have at times been found to be of value for purposes of correlation. Many cases are on record of their use for correlating sands and sandstones,[11] and we might make further use of them in determining the areas or rock formations from which the beds in question have been derived. They have thus been used at times to trace the source of sediments found in the shallower parts of the ocean bottom, as those of the continental shelf along the Atlantic Coast. The same method, however, seems rarely to have been applied to clay, although Hawkins has employed it recently for the Raritan clays of New Jersey.[12] As a result of his studies, he came to the conclusion that the currents which contributed these beds came from the northwest.

X. Other Factors

It must be borne in mind that where clays are being deposited as marine sediments, variation in successive beds may be due to shifting of the shore lines, so that the character of the sedimentation over a given spot may vary because the distance from the shore line changes. Land oscillations may also be responsible for alteration of marine and continental deposits.

Sedimentation of colloidal material goes on so very slowly that the accumulation of five feet of clay may represent the insoluble products of decay derived from the weathering of a very thick rock mass. Sedimentation in sea water is probably more continuous than in fresh water and results in more massive beds. Fresh water sediments often show very distinct stratification, sandy layers settling out in summer and the finer sediment in winter. Even the temperature of the water may affect the rate of settling.

XI. Coagulation and Texture

It is assumed generally that the deposition of marine clays is hastened by the coagulating action of salt water, since sodium chloride exerts this effect. Other dissolved salts may behave similarly. These coagulated particles of clay may enclose grains of silt and fine sand and carry them down also.

In fresh water, the quantity of coagulating agents is presumably so small as to have little effect, and so the colloidal particles in suspension remain more or less dispersed. Whether coagulated clay retains this structure after settling, and even after partial compaction, is not definitely settled, because thin sections of settled dispersed and also coagulated material do not seem to show a difference in structure. It is perfectly possible, however, for a coagulated clay to become dispersed after settling.

Sodium chloride flocculates a clay, but if, after settling, the NaCl is nearly all leached out, the clay becomes dispersed again. The soil chemist, however, still calls it a sodium clay.

In spite of the sorting that water may do, sedimentary clays may show a somewhat wide range of texture, many of the particles being larger than colloidal ones. Crystalline grains persist to very minute dimensions, and clays sometimes referred to as highly colloidal, because of their behavior, may not be truly of this type. Bentonite is claimed by Ross to be composed not of colloids, but of finely divided crystalline material, its high adsorptive power being the result of physical structure.

In any physical study of clays, the texture is a matter which warrants attention and involves often a mechanical analysis, prior to which the clay is usually dispersed with the aid of an electrolyte.

I have no intention of going into a discussion of the electrolytes used for dispersing fine-grained materials or the methods employed for making a

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[10] D. W. Ross, "Nature and Origin of Refractory Clays," *Jour. Amer. Cer. Soc.*, **10** [9] 704–20 (1927).

[11] P. G. H. Boswell, Mineralogy of Sedimentary Rocks, Chapt. V, p. 47, 1933.

[12] A. C. Hawkins, "Distribution of the Heavy Minerals in the Clays of Middlesex County, New Jersey," *Amer. Mineralogist*, **20** [5] 334 (1935).

fineness test, but I wish to suggest that there is abundant chance here for coöperation between the different groups utilizing and investigating clay.

There are many factors which may affect the result, such as the type of apparatus used, the nature of the electrolyte and its relation to the raw material being examined, the temperature of the water, and the character of the water itself. Some even claim that dispersion may be interfered with due to acidification caused by microörganisms and recommend toluene to prevent it.[13] A uniform standard method of testing would seem highly desirable.

XII. Sedimentary Clays Formed in Place

Little attention appears to have been given to the possibility that some sandy clays were originally deposits of arkosic sands or gravels, in which the feldspathic grains have weathered to clay after deposition.

The white sedimentary clays of Florida contain a large amount of quartz sand, sometimes even rounded quartz pebbles. How then could such large quantities of intimately mixed fine-grained clay and coarse quartz be deposited? The suggestion has been made, and it seems a reasonable one, that the deposit was originally a feldspathic sand in which the feldspar grains have since weathered to clay.

We find a somewhat analogous case in the so-called "feldspar" deposits of the New Jersey Cretaceous clays, where the material is found to be a coarse feldspathic gravel, consisting of quartz with more or less decomposed feldspar and pellets of white clay. Nearly all of the feldspar has been decomposed to a white clay, but occasionally pebbles of unaltered feldspar are found. The quartz pebbles are generally rounded or subangular.[14] If all of the feldspar in this deposit were decomposed it would be not unlike the white Florida clay.

XIII. Replacement Changes

Sediments, after deposition and even before consolidation, may undergo marked changes in composition, involving the substitution of one base or compound for another. When one mineral is substituted for another it is called replacement, but when one base is replaced by another it is usually termed base exchange.

The change of calcite to dolomite represents a not uncommon replacement process in calcareous sediments.

A more complicated case is seen in the potash deposits of New Mexico, where some of the gypsum has been replaced by halite and either of these later by polyhalite, the hydrous sulfate of potash, lime, and magnesia.

Flakes of volcanic glass are at times entirely replaced by plates of montmorillonite, and, since some of these ash deposits have accumulated in sea water, the replacement may have occurred during or following deposition. Biotite in sea water has been found replaced by glauconite. There are undoubtedly other examples, some of which may yield clay minerals.

More widespread, no doubt, is the mysterious process called base exchange, defined as "the alteration in cation composition of a solid resulting from treatment with a salt solution."[15] According to this definition, base exchange may operate either in colloidal particles or larger grains of mineral matter, and it is obvious that this action is not confined to fine-grained sediments or soils but may, during weathering, attack minerals in solid rocks, *e.g.*, as in hydrolysis. Opinions also seem to differ as to whether base exchange involves a change in crystal structure.

Wiegner[16] suggests that hydrogen may possibly enter a molecule of feldspar with the lattice structure still intact but with the interior degree of dispersion altered.

Lemberg,[17] on the other hand, cites as an example of base exchange the conversion of leucite, $KAl(SiO_3)_2$, to analcite, $NaAl(SiO_3)_2 + H_2O$, by treatment with sodium carbonate. Both are isometric, but the lattice structure is different.

The sodium of artificial crystalline sodium autunite can be readily replaced by calcium, potassium, barium, magnesium, and several metals.[18]

[13] W. Galliher, "Factors in Sedimentation Analysis," *Amer. Jour. Sci.*, **26,** 564 (1933).

[14] H. Ries, H. B. Kümmel, and G. N. Knapp, "The Clays and Clay Industry of New Jersey," *Geol. Surv. N. J., Final Rept.*, **6,** 180 (1904).

[15] W. P. Kelley and G. F. Liebeg, Jr., "Base Exchange in Relation to Composition of Clay with Special Reference to Effect of Sea Water," *Bull. Amer. Assn. Petrol. Geol.*, **18** [3] 358–67 (1934).

[16] G. Wiegner, "Some Physico-Chemical Properties of Clays, II. Hydrogen Clays," *Chem. & Ind.*, **50** [13] 103–12 (1931); *Ceram. Abs.*, **10** [7] 522 (1931).

[17] Lemberg, "Über Silicatumwandlungen," *Z. deut. geol. Ges.*, **28,** 519 (1876).

[18] W. T. Schaller and J. G. Fairchild, "Base Exchange of Artificial Autunite," *Amer. Mineralogist*, **4,** 265 (1929).

It appears very likely that base exchange may go on extensively in clays either during or after deposition, and Ross and Kerr[19] assert that it may go on without any breakdown of the clay molecule as a whole. The former suggests that certain clays and zeolites possess so open a crystal lattice that certain ions (bases) can be displaced and other bases substituted in their place without disruption of the primary space lattice.

Shaking a sample of ordinary clay with a sodium chloride solution or permitting the solution to filter through the clay[20] results in a displacement of some of the calcium or magnesium held in it by absorption or in combined form. It then becomes a sodium clay. Conversely, calcium or magnesium may displace sodium.

Sodium clays will probably be found only in deposits which have been covered with solutions of sodium salts. Such clays are very unstable and may be easily altered if exposed to solutions containing other cations; for this reason they are not common.

As far as the clay minerals are concerned, it is thought that only those with replaceable bases, such as calcium, magnesium, potassium, and sodium, exhibit much base exchange.

Since aluminum and iron of clays are said not to be replaceable to any extent, if at all, the kaolin minerals could not be expected to exhibit much base exchange.

Kelley has shown the strong reactiveness of montmorillonite toward base exchange by a simple experiment. Leaching the bentonite first with a solution of calcium chloride, he converted it to a calcium clay. In subsequent treatment with sea water, most of the calcium was replaced by other bases as the following table shows.

	Milli-equivalents/100 g. clay				Percentage of total			
	Ca	Mg	K	Na	Ca	Mg	K	Na
Before treatment	106.00	0	0	0	100.0	0	0	0
After treatment	10.85	48.35	6.9	39.13	10.3	45.9	6.6	37.2

We must not overlook the fact, however, that both leaching and base exchange may go on when clay deposits are no longer under water.

Base exchange is an important property of clays which may interest the geologist, ceramist, road engineer, agriculturist, and others, but the soil chemist has attracted the most attention to it. Care should also be taken not to confuse base exchange with adsorption.

Although much attention has been given to this problem by the soil chemist, it will still bear extended investigation insofar as clay deposits are concerned.

The critical study of the properties of clays is important from the practical as well as the scientific point of view, and the publications of the American Ceramic Society show the great amount of attention that has been given to them by the ceramic technologist.

I have endeavored to point out to you, from the point of view of the geologist, the problems that confront us in clay research, but many of them concern phenomena which might also interest the ceramic technologist.

Furthermore, as remarked earlier, there should, in addition, exist between the various groups interested in clays the closest possible coöperation in research work on the occurrence and properties of this material.

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[19] C. S. Ross and P. F. Kerr, "The Clay Minerals and Their Identity," *Jour. Sed. Petrology*, **1**, 55 (1931).

[20] See footnote 15.

DE-AIRING OF FLOOR TILE*

By Douglas F. Stevens and Robert P. Stevens

Abstract

The manufacture of shale and fireclay floor tile by the stiff-mud de-airing process is discussed. The effect of de-airing on capacity and power requirements, changes in drying and firing behavior, and the resultant effect on the absorption, density, and wearing qualities of the product are given.

I. Introduction

Formerly ground clay used for floor-tile manufacture was pugged in a 10-foot pug mill and then fed by gravity into the receiving hopper of a combination machine, thus giving the material an additional pugging process before it emerged into the augers and through the tile dies. In the conversion of the equipment now used for this purpose, the combination machine was moved to the pugging platform and an auger machine was installed below. Thus the combination machine (see Fig. 1) became a pug mill, *M*, and force feeder, *A*, into the lower de-airing unit. These two machines are connected with an air-tight gooseneck and steel connecting pipe, *P*.

The auger machine is driven by a 48- by 8-inch drive pulley at 150 r.p.m. The single gearing is enclosed and runs in oil. The pugged clay enters the auger machine vertically from the connecting pipe above and then makes a right-angle turn following the knives. The clay then quickly emerges into the de-airing chamber. Knives are used as the clay progresses across the chamber, giving the clay a kneading action and bringing the air to the surface where a maintained vacuum of about 28 inches removes the air from the clay. The vacuum line leads off from the top of this enlarged barrel chamber, shown in Fig. 1, and passes first through a clay filter, *F*, to remove any particles of clay that might follow out with the evacuated air. It then goes to the vacuum pump which is belt-driven off the main-line shaft. This vacuum line is 55 feet long and all possible elbows are eliminated by bent pipe to reduce friction losses in the line. The pump runs at 385 r.p.m. and is water-cooled. It has an automatic system of internal lubrication and is supplied with an oil separator which removes moisture from the evacuated air and also gives a force-feed lubrication.

The combination machine forces the pugged clay through a 10-inch sealing ring, *R*, before it makes its downward descent in the gooseneck. The die on the end of the auger shaft where the column emerges provides the other seal and gives a space of about 120 inches which is under the effect of total or partial vacuum.

This particular make of machine has only one stuffing or packing gland around which any leakage is possible. This is the main auger shafting, and it is provided with an adjustable ring to keep the packing tight. No other changes in equipment were necessary. A vibratory screen and two 2- by 6-foot plates with $^1/_2$- by $^3/_{64}$-inch holes are necessary for the fineness required to give the product the desired surface.

II. Results and Effects upon Properties

(1) Capacity

In this installation, actual capacity was reduced approximately 15%. This was overcome by increasing the auger speed on the de-airing auger machine 15%, thus restoring the capacity in terms of completed units. The production of tile is 28,000 pieces for an 8-hour period. The method of extrusion in the new auger machine is capable of a 25% greater volume of material at no increase in power, provided that this additional material is fed into the machine from the pug mill. A fluctuation in depth of clay in the pug mill produces a pronounced difference in the quantity of material produced.

(2) Power

The total power required for the de-airing process on this installation has neither increased nor decreased due to the counterbalancing of the greatly reduced die-friction losses *versus* the slight increase due to the additional pugging and the operation of the vacuum pump.

* Presented at the Annual Meeting, American Ceramic Society, Buffalo, N. Y., February, 1935 (Structural Clay Products Division).

(3) Clay Column

The increased plasticity eliminates all die lubrication. The plastic material has a greater density and there is less actual water used in pugging.

With less water of plasticity required, the dies for the new auger machine were ordered slightly smaller to compensate for the expected decrease in the drying shrinkage. The tile, however, were smaller than the standard size, due to the fact that the clay column under air evacuation did not swell upon emerging from the die as does the usual clay column. This absence of swelling compensated for the change in drying shrinkage. The original dies are still giving excellent results.

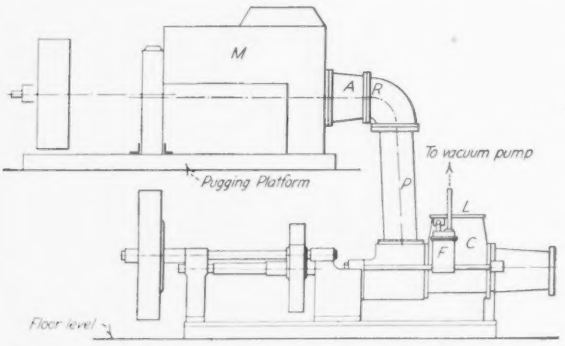

FIG. 1.—*Machinery layout:* *M*, pug mill; *A*, force feed auger; *R*, upper sealing ring; *P*, air-tight pipe; *F*, air-line clay filter; *C*, de-airing chamber; *L*, removable lid and glass window.

De-airing of the clay lessens lamination difficulties.

(4) Drying

Although less water of plasticity was needed in forming, the increased density, due to a smaller number of pore spaces, slowed up the rate of drying about 40%. Formerly this ware dried in 48 hours; it now requires between 66 and 72 hours to remove the moisture in the dry house. The drying shrinkage was reduced by approximately one-half.

(5) Firing

The firing shrinkage of the evacuated ware was increased. This is probably due to the increased density and material per unit, thus giving more clay grains per unit of length and volume in which firing shrinkage takes place.

The vitrification at constant temperature appears to be increased in the de-aired products.

A longer period for oxidation is necessary, but as there was already an elongation of this nature in the firing schedule no change was made.

Longer firing at the maturing temperature is necessary to darken the color of the tile. Fuel requirements are the same on firings of equal length for the de-aired material.

(6) Finished Ware

The absorption was greatly reduced in the evacuated ware and there was a general increase in weight per unit.

An abrasion service test, consisting of a 750-pound load mounted upon a single 2-inch face wheel with a 6-inch diameter which moves back and forth over the surface of a four-tile panel, indicates the superior wearing qualities of the evacuated material. The original rough back material was subjected to 120,000 trips and showed a wear of 0.01 inch. The de-aired shade A panel has run 168,000 trips and surface penetration is just noticeable.

The tile as produced by the evacuation process have a finer and more uniform appearance.

Contrary to expectations, the tile showed no increase in surface smoothness and as this was desirable a slight change in screening was made.

The de-aired ware has a slightly lighter color upon maturity and, by allowing the kiln to soak at this temperature, the desired darker colors are obtained.

There is a noticeable increase in good ware as body strains causing cracks and warpage are reduced. The evacuated ware runs about 90% first quality material whereas previously this was only between 75 and 80%.

III. Conclusions

De-airing of the clay column has (1) eliminated lubrication of the dies, (2) produced ware free from laminations, (3) greatly increased the density of the products, (4) increased strength and resistance to wear, and (5) reduced drying shrinkage and increased firing shrinkage; increased drying time and a longer maturing period for darker colors are slight disadvantages.

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THE PART OF THE BRICK MANUFACTURER IN THE BETTER-HOUSING PROGRAM*

BY W. D. RICHARDSON

ABSTRACT

In the future more and better houses will be available to persons of low incomes. Shall these be machine-made houses, prefabricated of standard steel units, the surfaces of stainless steel or enamel and the interior filled with mineral wool or other insulating material, or shall they be of brick? Three solutions of the problem are presented, individually or collectively: (1) use of brick of larger surface area, *i.e.*, square-end brick with their thickness the same as their width or square-face brick with their thickness the same as their length; (2) thin exterior and interior walls of brick, without plaster, so shaped as to be firmly interlocked by small tie brick, the intervening space being filled with insulating material; and (3) brick of low heat conductivity with a large number of small vertical holes. Brick manufacturers must break away from established usage and create a demand for a better product at less cost, in order to adjust their business to this time of economic revolution and to meet competition with other building materials.

I. Introduction

Prominent industrial engineers predict that a pronounced, distinctive feature of our progress in the years just ahead of us will be the better housing of our families, more and better individual homes for those of low and moderate incomes, houses equipped with more labor-saving and sanitary conveniences, as well as with educational and pleasure-giving instruments, than are now enjoyed by the most wealthy. In this era of residence building they vision machine-made houses of enameled sheet steel on steel frames, insulated between the exterior and interior surfaces with mineral wool, the whole prefabricated of standardized units that can be erected into a house in three days from the breaking of ground for cellar excavation to completion for occupancy.[1]

What does this mean to the brickmaking industry? Will manufacturers of brick be largely shut out of this most promising field of residence construction? Is this not the most serious problem before us today; what are we going to do about it? Will manufacturers continue to resist all attempts to produce a more economical brick unit and a more sanitary and less costly brick-wall structure? The purpose of this paper is to present a practical solution of this problem.

II. Size of Brick

Are we to continue to make the smallest brick in the world, although we continue to pay the highest wages for laying them? The writer has long felt that our American standard-size brick is too small and places the brick manufacturer at a disadvantage in competition with other building materials. A new standard should be not just a little larger, but a good deal larger, though not of greater volume than most European brick.

As an 8-inch wall is so well established in this

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[1] A. P. Sloan, "A Forward View," *Atlantic Monthly*, Sept., 1934.

country, it would not be feasible to change the length of brick, and as the width should be such that two headers plus the mortar joint equal the stretcher, the width should not be changed. Therefore, the only practical way of getting a larger brick is to increase the thickness. A new standard should have a definite ratio to the present standard, *i.e.*, a 2 to 3 thickness, as shown in Fig. 1. However, since reading of Heath's promotion of a standard module of masonry dimensions, the writer believes that the thickness of brick should be the same as the width, so that two courses and the mortar joint would make 8 inches. A variant of this size for still greater economy, as well as for architectural effect, would be to make the thickness the same as the length, 8 inches. To make the square-face brick light enough to be laid with one hand, larger vertical holes are cored, the holes being partially closed on the top side by means of a simple cell-closing mechanism, as shown in Fig. 1.

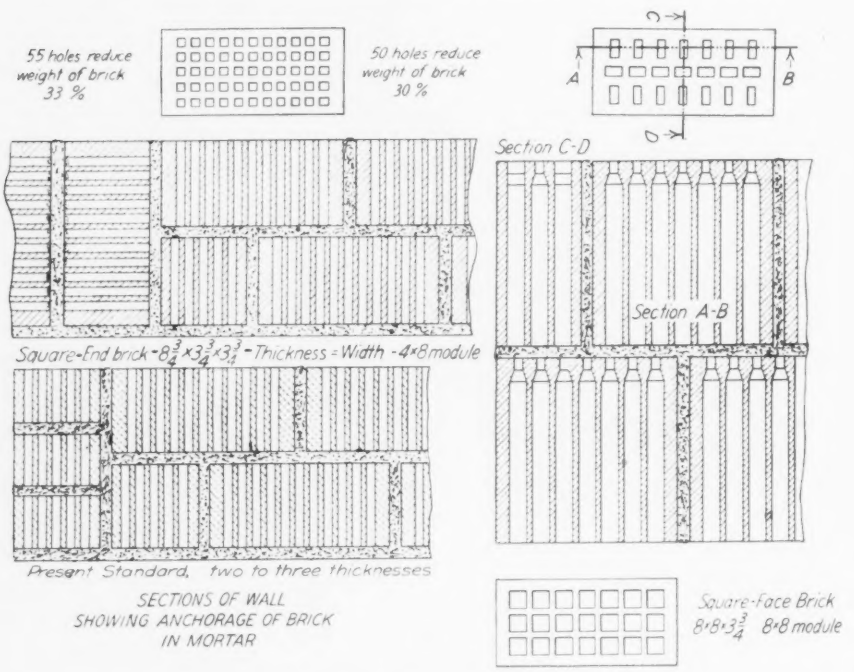
55 holes reduce weight of brick 33 %
50 holes reduce weight of brick 30 %
C
A
B
D
Section C-D
Section A-B
Square-End brick - 8 3/4 x 3 3/4 x 3 3/4 - Thickness = Width - 4x8 module
Present Standard, two to three thicknesses
SECTIONS OF WALL SHOWING ANCHORAGE OF BRICK IN MORTAR
Square-Face Brick 8x8x3 3/4 8x8 module

FIG. 1.—"Ankerlite" brick.

(1) Square-End Brick

The proposed square-end brick (thickness same as the width) contains about 6 cubic inches less volume than the Reichmass, a standard German brick (9.84 by 2.56 by 4.72 inches), which has proved for many years to be well within the limits of economical handling by the bricklayer.

In 1625, a law was passed in England standardizing the size of brick at 9 by 3 by $4^1/_2$ inches, and this size has been maintained practically the same ever since. It is evident that the proposed square-end brick would be much easier to handle than the English or German brick.

Letters, advocating a thicker brick, were sent to a number of brick manufacturers, requesting their opinion of such a change in size. Some of them approved the square-end brick; others brought up the objection that people had become so accustomed to the present size that a different size would not be well received and that such a size would violate an artistic sense of proportion. But is there a standard of taste in the ratio of the thickness to the length of brick? Is one brick more beautiful than another by reason of certain proportionate dimensions of its exposed surfaces? Has not the size of brick in all ages and all countries been governed by considerations of convenience of making and laying in the wall? Is not this a time of economic revolution when precedent has lost much of its appeal? "All permanent progress has been made by ignoring precedent," said Philip Snowden.

III. Heat Insulation and Moisture Resistance

In addition to the economy of a larger size brick, another important requirement that must be met to offset the claims of superiority of other structural materials now fabricated is low thermal conductivity, *i.e.*, transfer of heat from the warm to the cold side of the wall. It is known that a brick is a good conductor of heat, and the better it is made and the harder it is fired, the better the conduction; if not well made and hard fired, it

absorbs too much moisture, causing a damp wall that may be damaged by freezing. So, to maintain the superiority of the brick wall, it must be practically impervious or of low absorption and, at the same time, a poor conductor of heat.

IV. Lightweight Brick

Much research has been given in recent years to the production of insulating brick and, incidentally, brick of less weight. The first and most natural means of accomplishing this is by mixing with the clay combustible material such as sawdust, peat, lignite, culm, or ashes. Lower conductivity is attained, but the amount of nonplastic material that can be added to clay is limited (1) by the practicability of forming or molding by the most economical processes, and (2) by the crushing requirements of building codes. Moreover, the combustion of such materials in the brick is more or less detrimental to their color or appearance when used for facing.

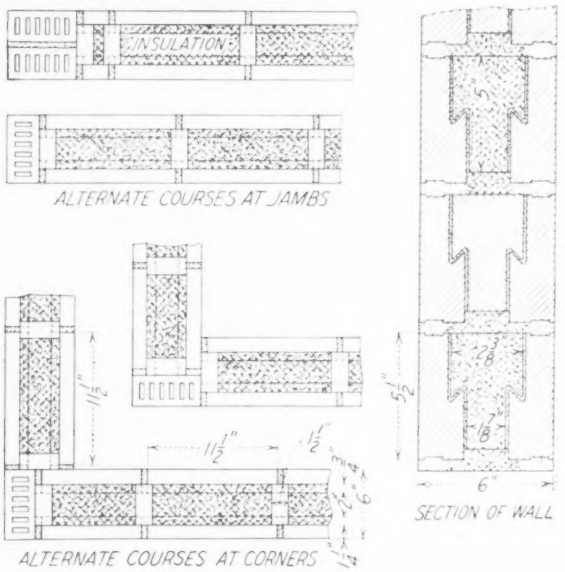

FIG. 2.—"Saneco" wall structure.

Research has lately been directed to a means of producing minute, closed cells in the brick body by the formation of gas or air bubbles chemically or mechanically in the clay dough or slip. Some very lightweight brick of very low conductivity have been made in this way, but the process so far developed, is too expensive for building brick. Moreover, such brick would not meet building-code specifications for absorption. It is an interesting and valuable piece of work and doubtless will find considerable use in some special clay products, such as acoustic brick and insulating fire brick.

V. Proposed Sanitary Wall

In the proposed "Saneco" (sanitary and economical) wall structure, shown in Figs. 2 and 3, the unfired, porous, gas-cell clay dough might be used, perhaps with a little cement added as an insulating filler between the thin outer and inner walls of the special shape brick of comparatively large surface area, such walls being tied together at every joint with a small brick registering with the stretchers and smeared tightly with cement mortar. It is not necessary that the filler have much strength, but it is believed that a plastic, porous filler would help the bond and be more practical than mineral wool. Where an extra strong wall is required, the filler may be of Haydite concrete reinforced with steel rods. In this structure there are no continuous mortar joints through the wall, as every tie brick is separated from the one above or below it by the thickness of the stretcher courses. The face dimensions of the stretcher, $11^1/_2$ by $5^1/_2$ inches, make two brick lay up a square foot of wall.

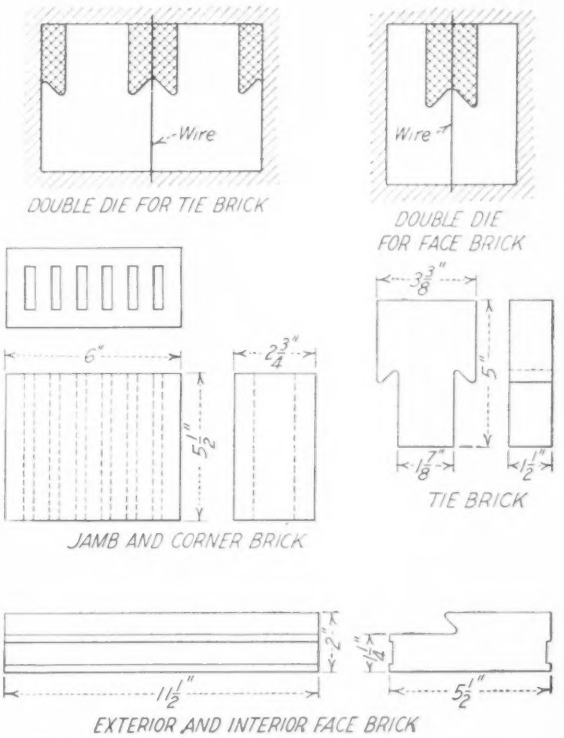

FIG. 3.—Brick units for "Saneco" wall structure.

The proposed thickness of the wall, 6 inches including the insulating filler, is 2 to 3 inches more than the prefabricated steel wall with insulating filler. The most logical construction of such a wall eliminates plaster entirely, the inside brick being smooth and of any desired color, glazed or unglazed, or the wall may be painted or papered if preferred. Partitions may be of brick of the same color and surface dimensions and a thickness of 2 to 3 inches, with horizontal holes to reduce weight.

Figure 3 shows the three brick units: stretcher, tie brick, and a brick for jambs and corners, and the dies for making the stretcher and tie brick on the auger brick machine. Figure 2 shows plans of alternate courses of the wall at jambs and corners and a section of the wall.

VI. Many-Hole Brick

Where an 8-inch wall is required, probably the most practical solution is the many-hole brick now extensively made in Germany. This brick has a large number of small vertical holes, as it has been proved that small holes have a higher insulating value than large holes and give the additional advantage of bonding the courses of brick together (Fig. 1). In making a full spread joint, small holes take up only a little mortar, while large holes fill up entirely, requiring a larger amount of mortar and more time of the bricklayers and tenders, or the mortar is spread around the borders, taking extra time and giving a poor joint and poor bond.

In a lecture before the technical section of the hollow brick industry in Berlin, W. Dawihl[2] gave the following report of tests of different kinds of brick, using a special electrically heated kiln and the Lamort heat flowmeter:

Brick	Heat conductivity(λ) in technical measure on dry brick λ	Water absorption (%)	
Solid	0.50	20	
Hollow	0.34	57	(holes 3 × 4 cm.)
Many-hole	0.29	20	(holes about 1 sq. cm.)
Fine-pored	0.24	63	

The results prove that Zellenziegel (many-hole brick), notwithstanding the smaller water absorption of its body, has less heat conductivity than a similar brick with larger holes and that the fine-pored brick has the lowest heat conductivity.[3]

VII. Conclusion

It is not an adequate answer to this pending situation in residence construction to say, as one manufacturer wrote, "We are in the business of supplying people with what they want and would be very glad to manufacture brick of this kind if there were a sufficient demand for it." The largest and most successful businesses today have been built up by creating a demand for something new and different, better and less costly, and not by waiting for a demand. Architects can not be expected to specify something for general use that must be made to order. The architect of a large mail-order house saw the drawings of "Saneco" wall structure (shown in Figs. 2 and 3) and asked, "Where can we get such brick. We do not carry brick in stock."

If the writer were actively engaged in brick manufacture, he would make something new, if it had positive advantages, even if other brick manufacturers would not go along. An effort should be made, however, to get united action by associations of brick manufacturers. Brick manufacturers may not be as powerful as the manufacturers of some other building materials, but they can control the situation by united action in making a better and lower-cost product.

SCHULTZ BUILDING
COLUMBUS, OHIO

[2] Chemisches Laboratorium für Tonindustrie, H. Seger and E. Cramer.

[3] *Ziegelwelt*, June 28, 1934.

DISCUSSION OF RICHARDSON PAPER

BY FREDERICK HEATH, JR.

Mr. Richardson brings out the need for careful study by structural clay product manufacturers of problems relating to design and dimensioning of masonry units. The designs proposed by the author reflect a growing tendency for larger brick sizes, also a need for more effective thermal insulation. Since the author has referred to the writer's promotion of a standard module of masonry dimensions, it might be of interest to summarize recent developments pertaining to this movement.

During the first three months of 1934, this subject was given consideration as part of the CWA activity in Syracuse, N. Y. This took the form of a questionnaire submitted to thirty-five Syracuse architects.

The general object of this project, of which this ques-

tionnaire was a part, was to survey and study the economic and industrial possibilities of metropolitan Syracuse and its trading area. The project was sponsored by the Chamber of Commerce, the Technology Club, and Syracuse University. The work was under the direction of the Mayor's Industrial Commission.

To find the sentiment of local manufacturers of building products, a meeting was held on March 9.

The following statement and proposal was read and considered by this group:

Proposal of Standard Units

Elimination of Waste

"At the present time, the dimensional standards of such stock building materials and products as brick, tile, block, windows, and doors are not definitely related to each other. As a result, there is difficulty in planning the assembly of these materials into a structure. This imposes a premium on the cost of construction through excessive waste of materials and labor.

"It is believed that coördination of the basic dimensional standards of these stock products will decrease the cost of building through elimination of waste. It is proposed to accomplish this by observing a standard unit of dimension or *module* for planning and for dimensioning stock materials and products."

Modular Planning

"A careful survey of prevailing standards and practices has led to the conclusion that the most practical rule to inaugurate modular planning is the following:

"*The principal masonry dimensions shall be in coincidence with a 4-inch module in horizontal and an 8-inch module in vertical planes.*"

NOTE: "Modular dimensions indicate center-to-center of joint distances. In accurate detailing, a mortar joint thickness, usually $1/2$ inch, is deducted from outside modular dimensions and added to inside modular dimensions."

Modular Materials

"Stock building materials and products shall be dimensioned to conform to this rule for modular planning. The following illustrates the revisions of present standard dimensions of stock products necessary to arrive at modular standards.

"*Brick.*—The modular standard would be based on three brick courses to 8 inches. The present standard size of common, sand-lime, and rough face brick is 8 by $2^1/_4$ by $3^3/_4$ inches. The modular standard for this grade of brick, which is laid up in joints averaging about $1/2$ inch thick, would be (average size) $7^1/_2$ by $2^1/_4$ by $3^1/_2$ inches.

"*Tile.*—The tile sizes most commonly used are either 8 or 12 inches high, 4, 8, or 12 inches wide, and 8 or 12 inches long. The modular standards would allow for the mortar-joint thickness to be deducted from these basic dimensions, making heights $7^1/_2$ or $11^1/_2$ inches, widths $3^1/_2$, $7^1/_2$, or $11^1/_2$ inches and lengths $7^1/_2$ or $11^1/_2$ inches.

"*Block.*—The block sizes most commonly used are 8 inches high, 4, 8, or 12 inches wide, and 16 inches long. As in the case of brick and tile, the modular standards would be compensated for joint thickness, making height $7^1/_2$ inches, widths $3^1/_2$, $7^1/_2$, or $11^1/_2$ inches, and the length $15^1/_2$ inches.

"*Windows.*—The old custom of basing window sizes on standardized glass sizes has given way in certain types of windows to an effort to establish modularly dimensioned standard masonry openings. A module of 6 inches has been used, but it is now proposed that standard masonry openings be in coincidence with a 4-inch module in width and an 8-inch module in height."

Endorsement of Modular Planning

The discussion by the manufacturers indicated merit in the proposal and confirmed the conclusions drawn. The manufacturers expressed a willingness to change the dimensions of their stock materials to those proposed, provided modular planning should become a practice among a majority of local architects.

In May, 1934, the Central New York Chapter of the American Institute of Architects endorsed the movement for consideration by their national organization and by the National Bureau of Standards. Similar endorsement was given subsequently to the movement as a project for investigation by the Bureau of Standards by the American Institute of Architects at its annual meeting in June, 1934.

National Bureau of Standards Proposal

The National Bureau of Standards has made a slightly different proposal, a plan for coördination based on a module of essentially $8^1/_2$ inches. This anticipates maintaining brick lengths and widths essentially as in the existing standard, but slightly increasing tolerance for brick thickness so that three brick courses can lay up to $8^1/_2$ inches. The investigation of the merits of different proposals for coördination is yet to be made, although the Bureau has found universal sentiment favoring coordination of the sizes of building products.

Mr. Richardson has suggested a square-end brick, or one that seems to be intended to lay up in 4-inch courses. While the dimensions of his Fig. 1 are slightly confusing, the economy of a larger brick is desirable. It would be the writer's suggestion that this brick be made to average $3^1/_2$ by $3^1/_2$ by $7^1/_2$ inches for laying in $1/2$-inch mortar joints, or $1/4$ inch larger in each of its dimensions, if it is a type of brick suitable for laying in $1/4$-inch joints.

Syracuse architects, informed of the proposal of the Bureau of Standards, have indicated clearly that the modular plan loses its desirability unless the simplicity of even inch dimensioning is observed. As evidence of this, the following paragraph is quoted from an illustrated article, "Modular Masonry and the Small House," by Willard H. Bennett, President of the Syracuse Society of Architects, appearing in the October, 1934, issue of *Architecture*.

If the value of the modular system be admitted, the next step is to determine the unit which will achieve the best results. Brick, block, sash, and other materials manufacturers are all anxious to adopt a unit which will cause the least disruption to their own processes of manufacture. One agency now investigating this question is advocating a module based on the present theoretically standardized brick size. But, with actual brick sizes

varying according to type of brick and locality of manufacture, is any pronounced advantage to be gained either by the brick manufacturer or the construction industry as a whole, by the adoption of a unit which retains the present minute fractional dimensions, cumbersome to use and a constant invitation to error? Is it not more logical to adopt a unit based on even inches as is given herewith which will be infinitely easier to work with, greatly reduce the chance of error, simplify every branch of practice, and finally, which will not penalize one manufacturing industry for the benefit of another?

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THE RESISTANCE OF CLAYS TO GAS PENETRATION*

By Frederick G. Jackson

Abstract

Oxygen must penetrate to the core of ware under fire in order to oxidize the carbon, sulfur, and iron content. The resistance of different clays to this gas penetration varies greatly. A form of apparatus is proposed for measuring this specific resistance. The value of this time of gas penetration is shown for valuing clay deposits.

I. Introduction

In firing ceramic ware, if the carbon, sulfur, and iron contained in the clay are properly oxidized, oxygen must penetrate to the core of each piece of ware and oxide gases must escape. The specific resistance of different clays to this gas penetration is a subject that has been given little study. It has, however, an important bearing on the time of kiln firing and, consequently, on the cost of production.

About ten years ago, the Bureau of Mines experimental car and crew, in one of its plant visits, studied the firing of ware made from a coarse fire clay containing much sulfur. The resistance to gas penetration of this clay was so small that the elimination of the sulfur was not a factor at all in firing the clay. Heat could be applied as rapidly as feasible. Firing was accomplished in five days. Another plant that was visited used a very colloidal, plastic clay containing less than one-half as much sulfur as the other clay. In this plant it was necessary to fire very slowly and carefully during the oxidation period, due to the resistance of the clay to gas penetration; otherwise the sulfur would not have been properly eliminated. Consequently, although the final temperature was lower, the firing time was ten days, twice as long as that at the other kiln.

Resistance to gas penetration is closely related to porosity and to plasticity. It is not, however, a function either of the unfired clay or of the finished ware but rather of the ware while it is under fire. It is conceivable that in some clays this resistance might change considerably during firing. It is therefore suggested that, in determining this property, tests should be made, not only on the unfired clay, but also on test pieces that have been partly fired. A group of test pieces should be placed close to the wicket of a commercial kiln. Several should be withdrawn at each of several predetermined temperatures and cooled before testing. It is suggested that these temperatures be 100°, 400°, 500°, and 600°C (200°, 750°, 925°, and 1100°F).

II. Proposed Apparatus

For making this test, an apparatus is suggested as shown in Fig. 1. The test piece, *A*, in the form of a thin tile of uniform and controlled thickness, is to be clamped with air-tight washers, *B*, into a frame, *C*, about 1 inch wide. This frame forms the base of a hollow four-sided pyramid, *D*. At the apex of the pyramid is a stopcock, which communicates with a much larger closed chamber, *F*. The ratio of the volume of chamber *D* to chamber *F* must be known, assumed to be 20 to 1. Chamber *F* bears a vacuum gage, *G*, and a connection through a stopcock, *H*, to an ordinary laboratory vacuum water pump.

III. Operation

With the upper stopcock closed and stopcock *H* open, the chamber *F* is first evacuated to a definite degree (as near a vacuum as can easily be attained by the pump), as shown by the gage. The cock, *H*,

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* Presented at the Annual Meeting, American Ceramic Society, Buffalo, N. Y., February, 1935 (Structural Clay Products Division). Received February 4, 1935.

is then closed. A definite low pressure should be decided on for the starting pressure and should be the same in all tests made.

To make the test, the upper stopcock is opened and a stop-watch started; $^{20}/_{21}$ of the reduced pressure of the chamber, *F*, is thus applied to the inner surface of the test piece, while its outer surface is open to the air where it is not covered by

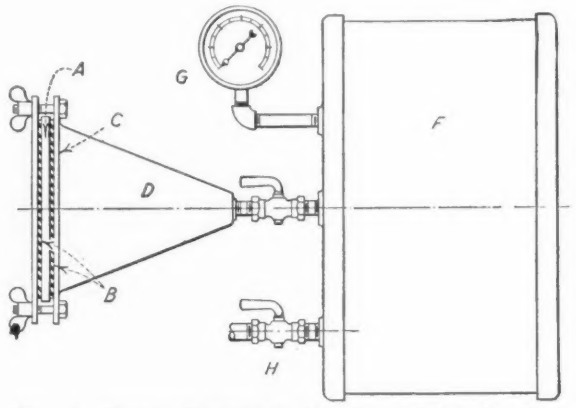

FIG. 1.—Proposed apparatus for determining the time of gas penetration.

clamp or washers. The resistance of the exposed body of the test piece will fix the speed at which air will penetrate the test piece to restore equilibrium. The speed of penetration will thus be shown by readings of the stop-watch at definite points of partial vacuum as shown by the gage.

IV. Proposed New Unit of Resistance

It is suggested that the resistance of the sample shall be characterized by the time that elapses before the inside pressure is built up by air penetration to half an atmosphere. This might be known as the time of gas penetration.

V. Further Work Needed

Laboratory experiments will be needed to determine the following factors: (1) the size of the test pieces, perhaps 6 by 6 inches; (2) their thickness, which probably should be just enough to avoid collapse under reduced pressure on one side; (3) the starting pressure in the chamber, *F;* (4) the best relative size of chambers *D* and *F;* and (5) the significance of preheating.

For this purpose, a series of samples of standard clays from operating plants should be collected and tested as above. The time that each plant requires to fire a kiln of brick (not tile) should be known, or, better, the time required to attain 600°C (1100°F). These factory firing times should be compared with laboratory results on times of gas penetration for the same clay preheated to different temperatures. From these comparisons, the most significant degree of preheating can be determined.

VI. Value of Unit

This unit should be of service in determining the commercial availability of clay deposits. A clay with a long time of gas penetration and containing constituents that must be oxidized will need a longer firing schedule than another clay more easily penetrated by gases. The consequent extra cost of labor and fuel and the reduced plant capacity should be assessed against such a clay in determining its merits.

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SOME ENGINEERING PROBLEMS ENCOUNTERED IN MAKING A 200-INCH TELESCOPE DISK*

By G. V. McCauley

Abstract

An account is given of the preliminary preparations attendant upon the manufacture of a 200-inch glass disk weighing 20 tons. This is followed by a description of the mold design, materials, and construction, the casting practice, the annealing kiln and annealing procedure, and means for finishing, crating, and loading.

I. Introduction

(1) Engineering Aspect

Associated with every new achievement in our physical world, be it the discovery of research, the application of discovered facts to practical usage, or the fabrication of material objects, much engineering is involved. The research worker often spends far more time devising sensitive instruments, building adequate mechanisms, and assembling apparatus than is required for him to observe the facts that will prove or disprove the theory involved. The inventor throws away many contrivances before he perfects one that will turn the discovered fact of the research worker into a servant of humanity. And so also the manufacturer of material objects must devise and construct machines and methods for the fabrication of each new product requested.

Articles of manufacture and the engineering problems they provide appear large or small only by comparison with others of their own kind. If we should ask for a twenty-ton iron casting from a modern foundry, no problems out of the ordinary would be involved. The foundryman would proceed with cupolas, cranes, ladles, and flasks already in place as standard equipment. On the other hand, a request for a single glass article weighing twenty tons would create quite a different idea of size in the mind of the maker of technical glassware. In his inventory of plant and equipment, he would see melting tanks for which, with no allowance for cullet, twenty tons of glass represented the total output for twenty-four or more hours. He would see glass being transferred from the tank to molds by punties, a few pounds at a time, or by feeders from which glass is delivered in gobs at a maximum rate of 30 to 40 pounds each minute but could be flowed in a continuous stream at a possible rate of 6000 pounds each hour. He would see the molded articles being carried by boys on asbestos-covered paddles from the presses to the leers incapable of accommodating any article whose dimensions exceeded more than a few feet in any direction. In all this he would realize that for the manufacture of the twenty-ton article he possessed only the facilities for melting the special glass required, the knowledge to make the glass and mold it while hot into form, and the assurance that he could free the article from internal stresses by known laws of annealing, but that he would be required to modify his methods and equipment for most of the processes. This, in fact, represented the situation at Corning Glass Works in October, 1931, when the request came to cast a 200-inch telescope disk for the California Institute of Technology.

(2) Earlier American Disks

Before proceeding with an account of the manufacture of this, the largest glass casting ever attempted, it is only fitting that the achievements of the American pioneers in similar enterprises be here mentioned. First of these was the 62-inch disk, cast in 1895 by the Standard Plate Glass Company of Butler, Pa., for John Peate, who later polished the mirror for American University. The telescope, however, was never completed. Next, following the impetus given to the manufacture of optical glass in this country during the World War, Donald Sharp and Walter Rising made several blanks at the Spencer Lens Company in Hamburg, N. Y. The largest of these castings, 40 inches in diameter, was made in 1921 and was subsequently figured by James B. McDowell for use at the Stewart Observatory in Arizona. A year later, Corning Glass Works made of Pyrex-brand chemical glass the first of several small mirror disks produced prior to 1932. The largest of these was approximately 27 inches in diameter. They are in use today as

* Presented at the Annual Meeting, American Ceramic Society, Buffalo, N. Y., February, 1935 (Glass Division). Received July 3, 1935.

auxiliary equipment at Mount Wilson and other observatories. In 1927, under the supervision of A. N. Finn, a disk 69 inches in diameter was cast at the Bureau of Standards. This disk was subsequently figured by J. W. Fecker of Pittsburgh and now forms the reflector for the Perkins Observatory telescope at Ohio Wesleyan University, Delaware, Ohio. In this connection, it is only fair to mention the very great achievement of Elihu Thomson of the General Electric Company at Lynn, Mass., under whose direction was developed an entirely new process of making disks of fused silica by spraying grains of crystal quartz through a hydrogen-gas burner and fusing them in place on the face of the blank which was gradually formed by passing the burner repeatedly over the area of its surface. In this way, Dr. Thomson succeeded in building up disks 60 inches in diameter and over 9 inches thick. While the process lacks certain minor refinements to make perfect disks possible, it is felt that these could be made, were it considered necessary to make the very much greater expenditure to secure disks of fused silica by this method rather than obtain them of low-expansion glass by accustomed methods of glass manufacture.

The disks cast at the Spencer Lens Company and at the Bureau of Standards are of particular interest in connection with the present discussion. It is true that both were considerably smaller than the 100-inch reflector cast by the St. Gobain Glass Works of France for the Hooker telescope of Mount Wilson Observatory; for that reason perhaps they did not attract much interest from an engineering viewpoint. Of scientific interest, however, they served to demonstrate the principles of annealing presented in 1920 by Adams and Williamson. These principles, though perhaps not mathematically exact, nevertheless have enabled us to eliminate all guesswork from the process of annealing and have given us the assurance to undertake the manufacture of any article of glass without uncertainty regarding our ability to anneal it. This constitutes an achievement for which glass manufacturers and technologists are daily grateful.

(3) General plan

Returning now to our subject, which relates to the manufacture of a 200-inch disk, attention is called to the fact that the nature of the problems involved, as in any undertaking, is determined in large measure by the particular plan of action or method of procedure adopted. A full understanding of these problems is possible only when that general plan is known. We shall therefore state the method by which we undertook to cast 20 tons of the lowest expansion borosilicate glass ever before worked commercially into a single article slightly over 200 inches in diameter, and then proceed to discuss the engineering problems encountered at successive stages of the operation.

In stating this general plan, we do not wish to imply that large disks can not be made in any other manner. We desire to state that after due consideration of the working space available, of the equipment on hand, of the working characteristics of the glass, of the possible experimental element associated with each step, and of the cost to our customer, we chose to melt the glass in a tank, transfer it from the tank to the mold in large hand-operated ladles, and to anneal the article in a periodic, electrically heated kiln. The problems arising from this choice of procedure will now be discussed.

II. Preparations

(1) Mold Material

Our first problem was to find or make a suitable material from which a mold could be constructed. In this, as in every other instance, an attempt was first made to employ stock articles of commerce in order to avoid expensive research and development and to insure quick delivery of material. Starting with the knowledge of the characteristic properties required of the article at each step, the search for that article began. Thus for the mold material was sought porosity for the escape of gas, thermal insulation to prevent a radial flow of heat from the disk, friability to insure easy removal of the mold from the glass and to keep the compressive strength of the mold below the tensile strength of the glass, freedom from fluxes that cause adherence of glass and mold, absence of materials that disintegrate to liberate gas when covered with molten glass, and lightness of weight to lessen a load that with every precaution is of necessity very large.

To find all these properties to a fair degree of perfection in a single commercial article must indeed be considered a stroke of good fortune. Naturally the search started among the many high-temperature insulating brick familiar to glass

manufacturers. Selection was made on actual performance in experimental tests. These consisted of pouring hot glass from a small hand ladle into a mold nine inches square and two inches deep made of standard brick shapes. Two such trials yielded a satisfactory material which chanced to be the high-temperature insulating brick of the Armstrong Cork & Insulation Company of Lancaster, Pa. While fulfilling most of the requirements demanded of it, this brick gives off small bubbles of gas and adheres to the glass when held for several hours in contact with the latter at temperatures above 1100°C. As the particles of the brick fluxing with the glass separate easily from the body of the brick on cooling, no fractures of the glass occur. The result aside from the bubbles is merely a rough surface. Resorting to the foundryman's practice of coating the mold with a wash of silica flour to produce a smoother surface corrects the evolution of gas as well. To insure the building of the mold, there was needed now only some type of cement with which large blocks could be built up from standard brick shapes. From among several recommended by the Armstrong Company, Hytempite was selected.

Thus were solved the problems of a mold material. Possibly other brands of high-temperature insulating brick and cement would have served equally well. As the ones selected suited their purposes and could be obtained readily, there was no need of seeking further.

(2) Ladling Technique

Next in order were the problems attendant upon ladling. As glass is not worked by this method at Corning, experience and equipment were lacking. The characteristics, however, of Pyrex-brand glasses were known to demand different ladling practices than those employed for window glass. These practices and the need of applying heat to the mold while casting as a means for removing unavoidable blisters were learned in making a series of small disks required as auxiliary mirrors for the 200-inch telescope. Incidentally, at the same time, two men were discovered in the employ of the Company who had had previous experience as glass ladlers in the now obsolete cylinder method of producing window glass. With the training acquired in making the small disks referred to above, these men became familiar with the working of the disk glass. This discovery solved the problem of procuring ladlers whose services in this capacity were needed only intermittently as preparations for casting each succeeding disk were completed.

(3) Melting and Working a Special Glass

At Corning Glass Works, melting is done for the most part in tanks; and at the close of 1931, as at many another glass factory, several of these units were idle. It was only natural then to choose this type of melting for the manufacture of the large disk. Experience alone, however, would have led to the same choice even though no tank were available and the expense of building one for the purpose had been involved because of the more uniform glass composition which is known to result from melting in a single large tank instead of in many separate pots.

The decision to employ a tank, however, did not at once remove all difficulties of melting. The particular glass which had been selected for the disk because of its high degree of chemical durability and its expansion value of only 2.5×10^{-6} per degree centigrade had never been melted in quantities of more than a few hundred pounds. Therefore, it was necessary to establish the technique of melting and working practices suitable for obtaining glass of good quality in large quantities. For this purpose, a small continuous tank of seven tons holding capacity was employed. Two fillings of the tank sufficed to determine the proper glass composition, the melting temperature, and the melting rate. Working the unit as a day tank with a ladle and track assembly temporarily installed and capable of handling three hundred pounds of glass in each ladleful, the technique of ladling glass without filling it too full of blisters was acquired. At the same time the maximum free cooling rate of a block of glass comparable in thickness to that of the 200-inch disk was established and the maximum time the ladles could contain the hot glass before reaching a scaling temperature was determined.

III. Final Preparations

(1) Conveyance for Disk

With the preliminary experimental work completed, operations were now transferred to the factory site which had been selected for the actual casting of the disk. This location was that of an abandoned tank situated between two other tanks

normally used for melting Pyrex-brand glasses. The smaller of these two was available for melting the glass needed in this work. The space allotted for carrying out the casting and annealing operations was only 53 by 36 feet and had to contain the annealing kiln and the mold, with its overhead oven dome, besides the necessary electrical and control equipment for the annealing kiln. As the elevation of the top of the mold during casting was fixed by the glass level in the tank, and as this was only $17^1/_2$ feet below the roof trusses of the building, an overhead traveling crane of the required capacity for placing the mold and disk into the kiln or setting the kiln over the mold and disk was out of the question. The problem of transporting the mold and disk was accordingly solved by using a 60-ton screw hoist (Fig. 1) which could be installed in the factory cave and moved on rails directly beneath the pouring oven and annealing kiln. This hoist has a vertical screw speed of 2 inches per minute and can be moved along the rails by a hand-operated drum and cable at any desired speed. It was necessary to make only one change in the standard stock hoist as manufactured by the Whiting Corporation at Harvey, Ill. To place the screws under the load and at the same time keep them from projecting into the working space of the top of the hoist when in its lowered position, the nuts of the screws were located in the carriage of the truck instead of in the moving table where they are normally placed. This change necessitated trenches at each side of the carriage rails to accommodate the screws as the hoist was moved along its track in the lowered position. To protect the screws from the waters of the Chemung river, which flow directly north of this site and sometimes rise above this level, iron casings were constructed to house the screws when in their lowered positions. These casings also serve as containers for lubricant and as protection to the screws against damage from blows.

(2) Casting Oven

Having chosen the screw hoist for conveying the disk and its mold, both the oven dome which covered the mold during casting and the annealing kiln in which the disk was cooled had to be suspended from overhead structures to permit the passage of the hoist with its load of mold and disk beneath them. The first of these (Fig. 2) is hung from a carriage on wheels which permits its removal along overhead rails from the site occupied while the disk is being cast. This construction provides the necessary space for the building of the mold on the table of the hoist. Early in the program the practice had been established of

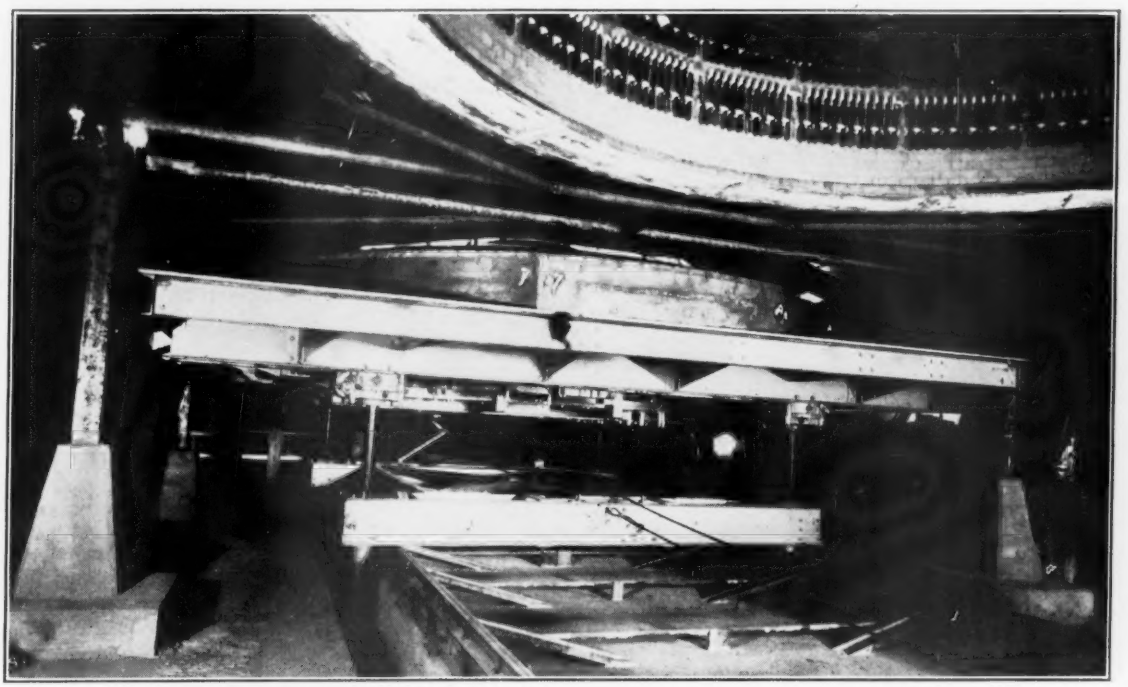

FIG. 1.—Sixty-ton screw hoist for conveying the 200-inch disk through its manufacturing processes.

building the oven domes for covering the molds during casting with the same insulating brick that had been selected as mold material. In this manner the weight of the suspended dome needed for the large disk was reduced in weight by approximately twenty-eight tons. Also the use of high-temperature insulating brick for this purpose, as furnace men are fast learning, is an excellent way to conserve fuel and time in firing periodic kilns. The annealing kiln is suspended from a system of steel beams supported on columns in a manner to be described later.

Besides being suspended from an overhead support and capable of being moved out of the way to make space for the building of the mold, the pouring oven had to possess many other features. As no stack was possible, vent holes had to be supplied in the crown for the escape of exhaust gases.

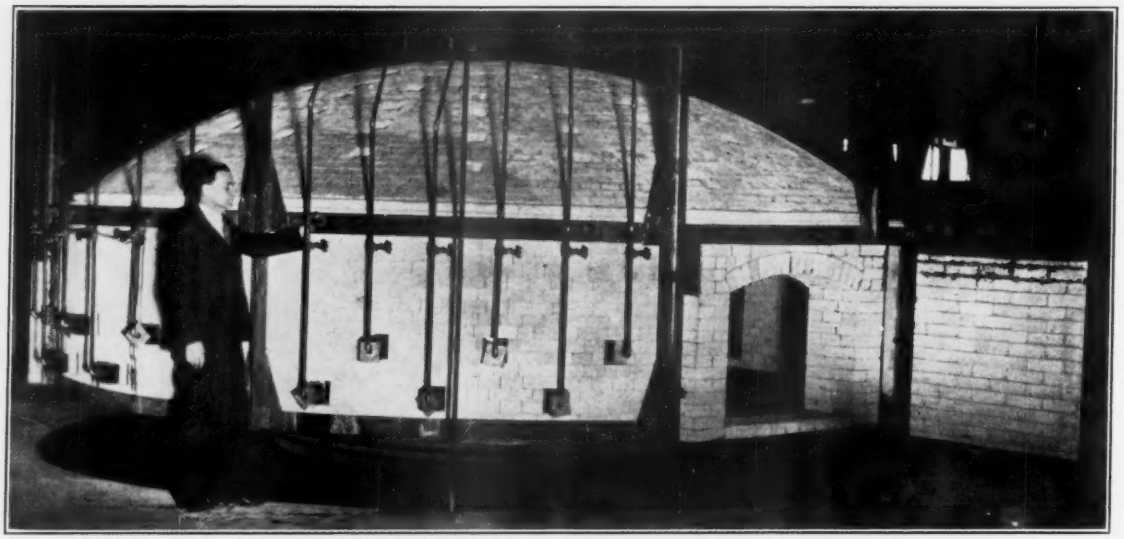

FIG. 2.—Pouring oven of high-temperature insulating brick used for casting the 200-inch disk.

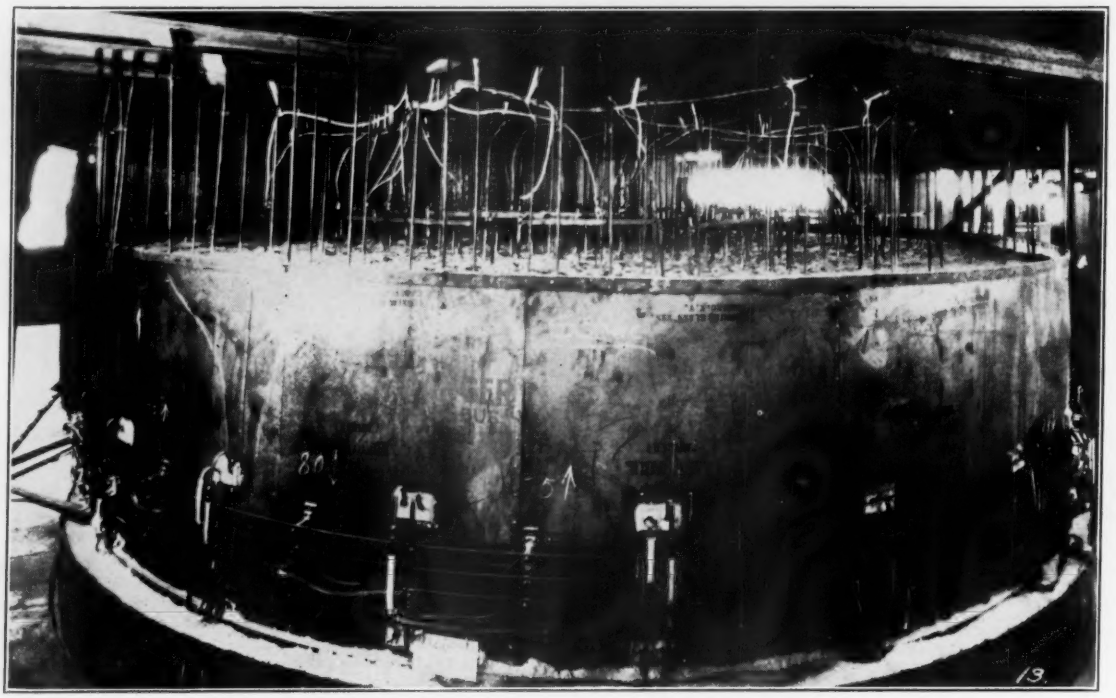

FIG. 3.—Assembled view of the annealing kiln for the 200-inch disk.

One hundred seventy-four of these openings serve as outlets for the exhaust gases whose volume was determined from an estimate of the natural gas fuel required for heating to the maximum temperature. Doors for the ladles were needed that would operate without interference either with the ladle tracks above or the floor and mold below and when operated would present their heated surface always to the oven away from the workmen. To make removal of the accumulated glass on the door sill readily possible and to prevent the adherence of glass which accidentally comes in contact with the door jambs as the ladles pass in and out, these are washed with the silica flour coating that is used on all surfaces of the mold in contact with glass.

(3) Annealing Kiln

(*a*) *Construction.*—The building of the annealing kiln (Fig. 3) presented many problems of design and construction though none of them was particularly difficult. The general design (Fig. 4) is that of a can hung from above with its open end downward. Into this, the mold containing the disk may be raised by means of the screw hoist on which, beneath the mold, is built the closing end or cover to the can. Heat losses are reduced by nine inches of cork insulating brick, *B*, and nine inches of Sil-O-Cel powder, *S*, in all walls. Additional thermal insulation is provided by having no metal connection between the thin outer shell, *A*, of the kiln and the interior framework. A ring of insulating brick, *R*, serves to space these parts and retains the insulating powder between them. This construction also takes care of the differential expansion between the outer shell and the interior of the kiln. Further provisions for expansion are to be found in the absence of any rigid coupling between the metal, *M*, of the top of the kiln and that of its side walls, *W*, and in the use of many small plates in place of a single large one wherever a horizontal bed plate of metal is necessary in the construction as, for instance, in the top of the kiln for attaching heating elements, *H*, and supporting the insulation at this point, in the mold frame for supporting the mold, and under the mold frame for supporting the 9-inch layer of insulating brick together with the heating elements, *E*, for the bottom part of the kiln. Short circuiting of the heating elements is avoided by passing the leads of each heater through proper insulating bushings, *I*, and by employing only 35 volts for the power supply.

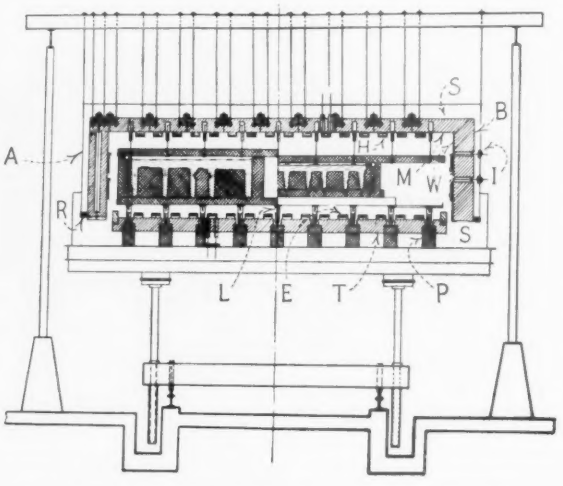

FIG. 4.—Cross-section sketch of the annealing kiln.

The lower part of the kiln located on the table of the screw hoist required special treatment to carry the load of the mold and disk. Solid piers, *P*, 9 inches square and 9 inches high, of high-temperature insulating brick carry a bed of $^3/_8$-inch iron plates, *T*, beneath which is 9 inches of Sil-O-Cel powder. Directly over these piers are others of the same material $4^1/_2$ inches high on which is a 9-inch square iron plate to carry the legs, *L*, of the mold frame. In order that the latter may expand freely about its center, each leg rests on a steel ball and has a right-angle stop at the corner toward the center of the disk. Nine inches of insulating brick on the plates above the Sil-O-Cel powder now completes, except for the bottom heating elements, the construction of the lower part of the kiln.

The location of all suspension rods, the supporting legs of the mold frame, the brick piers on which they rested, the spacing and direction of the steel ribs of the mold frame, and the beams of the screw hoist itself could not be haphazard. These conditions were all determined by the arrangement of the electrical heating units in the top and bottom of the mold. With 516 terminals to bring through to the outside of the kiln in these two locations it was desirable to plan carefully to avoid obstructions in assembly. As these heaters (Fig. 5) are of the standard rectangular type furnished by the General Electric Company they arrange themselves most readily in rows. To insure uniform heating over the entire inner area

of the kiln, the spacing of the rows is kept as close as possible. Thus the entire areas of the top and bottom of the kiln directly above and below the mold and disk when in position are covered with identical arrangements of these heating units. Two rows of standard wall-type heaters (Fig. 6) hang on porcelain hooks and between porcelain spacers regularly supplied by the manufacturers and built into the insulating brick wall of the kiln. The use of many heaters makes it possible to maintain a given kiln temperature with the actual temperature of the heating ribbons only slightly above this value at any time. The use of rugged heaters of greater rating than required eliminates overheating and failure.

(*b*) *Temperature Control.*—For temperature regulation, ten base metal thermocouples connected to automatic controllers are employed. Three of these thermocouples are located in the top of the kiln at symmetrical points with respect to its center. Three others occupy similar positions in the bottom. These, however, are displaced approximately 60° with reference to those in the top. The remaining four thermocouples are situated at equally spaced distances around the side wall of the kiln midway between

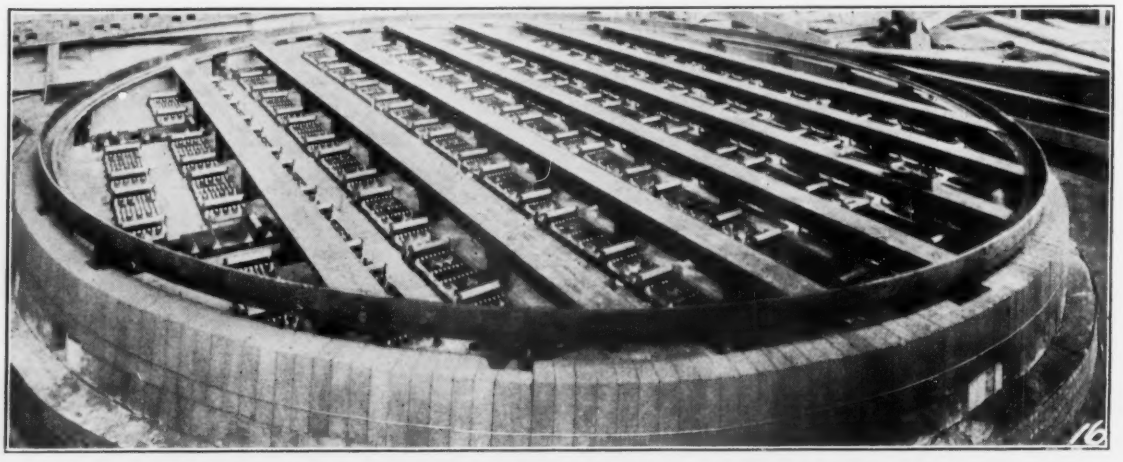

FIG. 5.—Arrangement of heaters below the disk and steel frame for carrying the mold and disk.

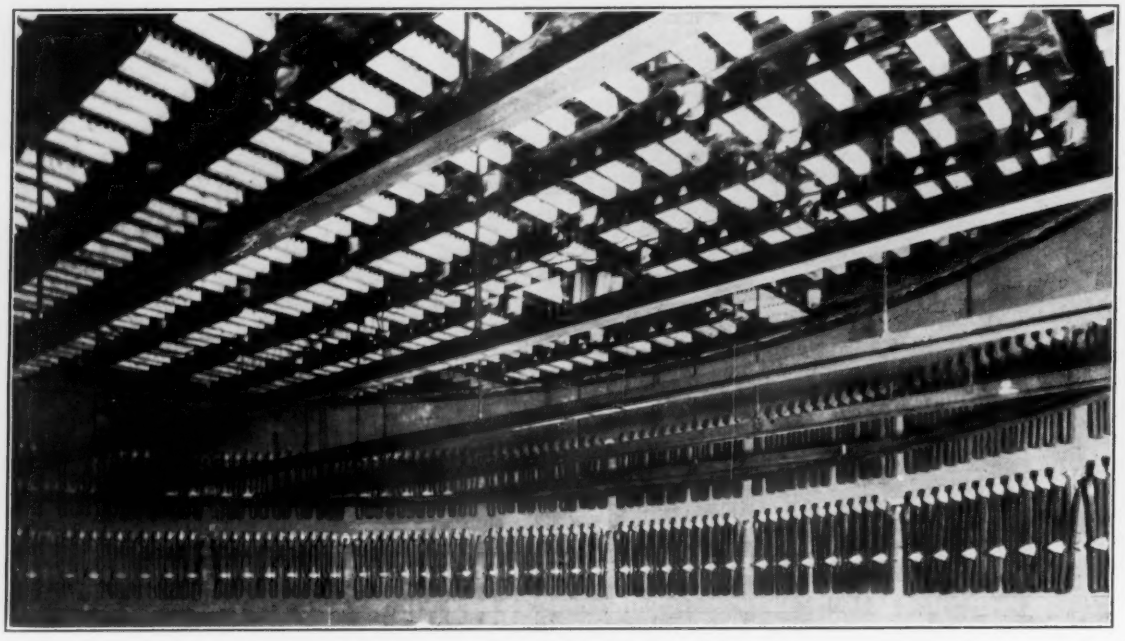

FIG. 6.—Top and side-wall heaters of the annealing kiln.

the two rows of side-wall heaters. All thermocouples are installed in open-end tubes and have their junctions flush with the inner face of the heater ribbons. This type of installation insures rapid response to temperature changes while at the same time the couples are protected from the direct radiation of the heaters.

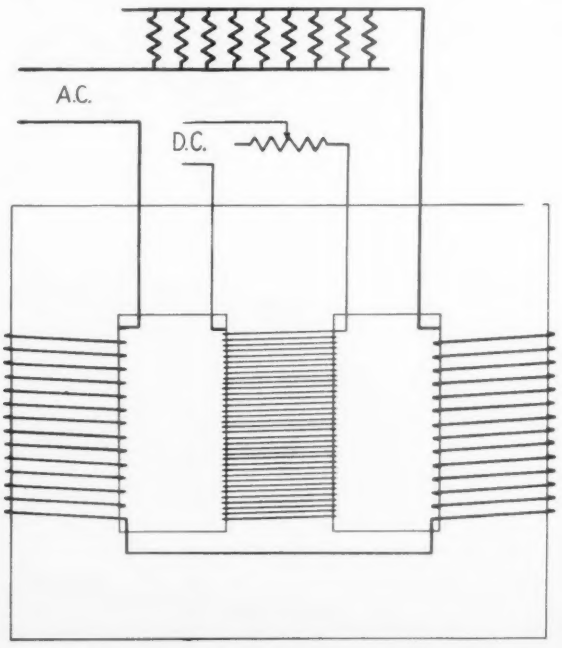

FIG. 7.—Diagram illustrating the use of a theater dimmer reactance for power control (reactor).

The control units themselves are somewhat different than is customarily employed for regulating power to glass annealing kilns. This type of control was chosen for its simplicity of operation, its low cost, and its installation advantages. It is what is commonly known as a theater dimmer reactance and as such is used to produce a gradual and continual change in the brightness of theater lighting. In electrical parlance it is called a reactor (Fig. 7) and consists of a closed core of laminated iron across the middle of which is a dividing core, or leg, of the same material built integral with the whole. Coils of heavy copper are wound on the outside legs of the frame to carry the power supply of alternating current, while around the central leg, or core, is wound many turns of fine copper through which a small direct current flows. It is the controlled variation of this latter which governs the power cir-

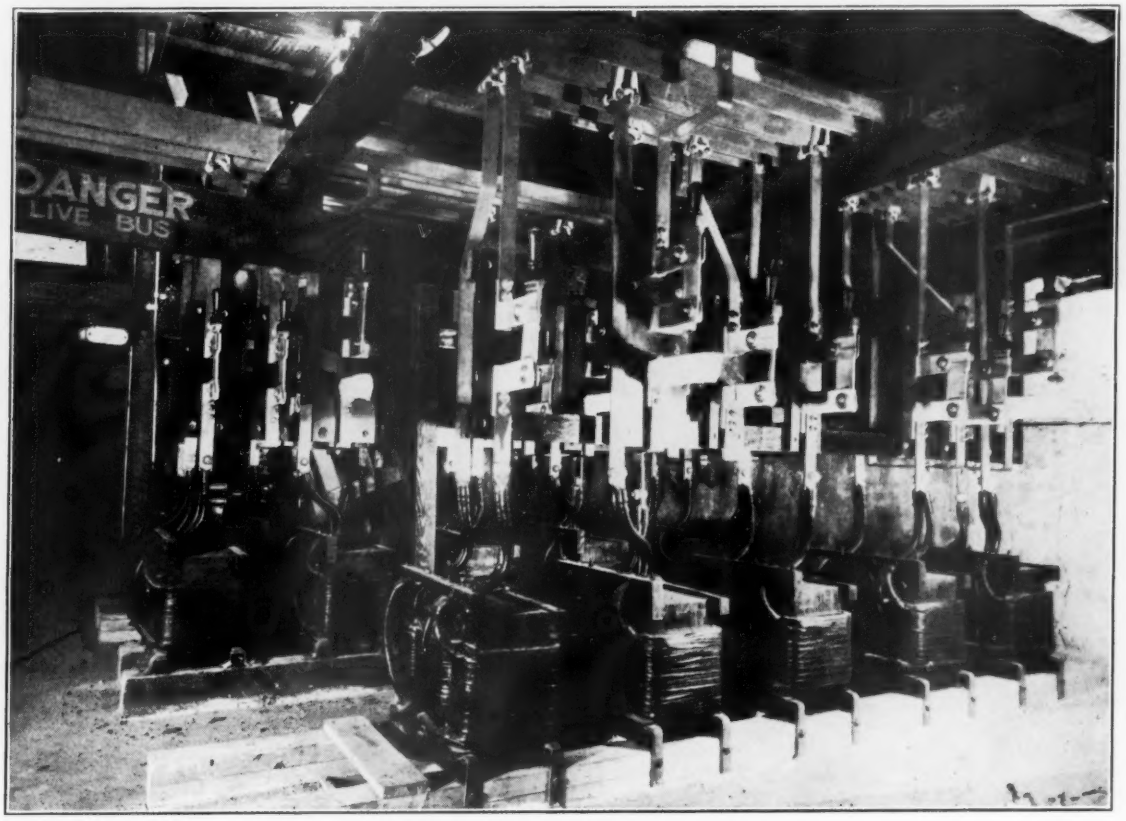

FIG. 8.—Group of reactors controlling the power to the annealing kiln.

culating through the alternating-current coils. With the reactors employed in this work, it is possible to vary the alternating current from 50 to 500 amperes in each power unit by interrupting with the controller switch a direct current of less than one ampere. The chief objection to their use is the low power factor which results when operating under less than full load. In the work of making a single large disk, however, this is of little consequence. These reactors (Fig. 8) were furnished by the Westinghouse Electric & Manufacturing Company of Pittsburgh.

(*c*) *Power Circuit Employed.*—The actual circuit connections of a single power and control unit is shown in Fig. 9. The alternating current from either of two independent sources received at 2200 volts, three-phase, is transformed to 35 volts, single-phase, with three lighting transformers. This low-voltage current passes in series through the alternating-current coils of the reactor and its group of heating elements. A small transformer of 5 kilovolt-ampere capacity furnishes, from the 2200-volt primary circuit, alternating current at 110 volts to drive the controllers and a motor generator unit which delivers the 110-volt direct current for operating the reactors. This direct current passes in series also with a regulating rheostat, *R*, and the mercury switch, *S*, of the temperature controller. These latter are stock Wilson-Maeulen instruments (Fig. 10)

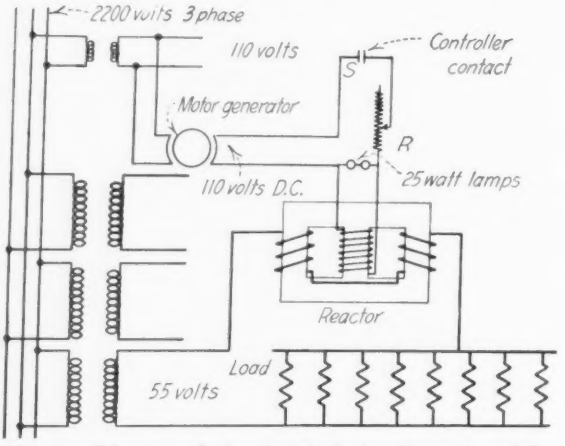

FIG. 9.—Diagram of the electrical circuit employed for heating the annealing kiln.

with a range of 75 to 625°C and were obtained from the Foxboro Instrument Company of Foxboro, Mass. They were chosen for their ruggedness and for their open circular scale which permitted the easy addition of a vernier with which

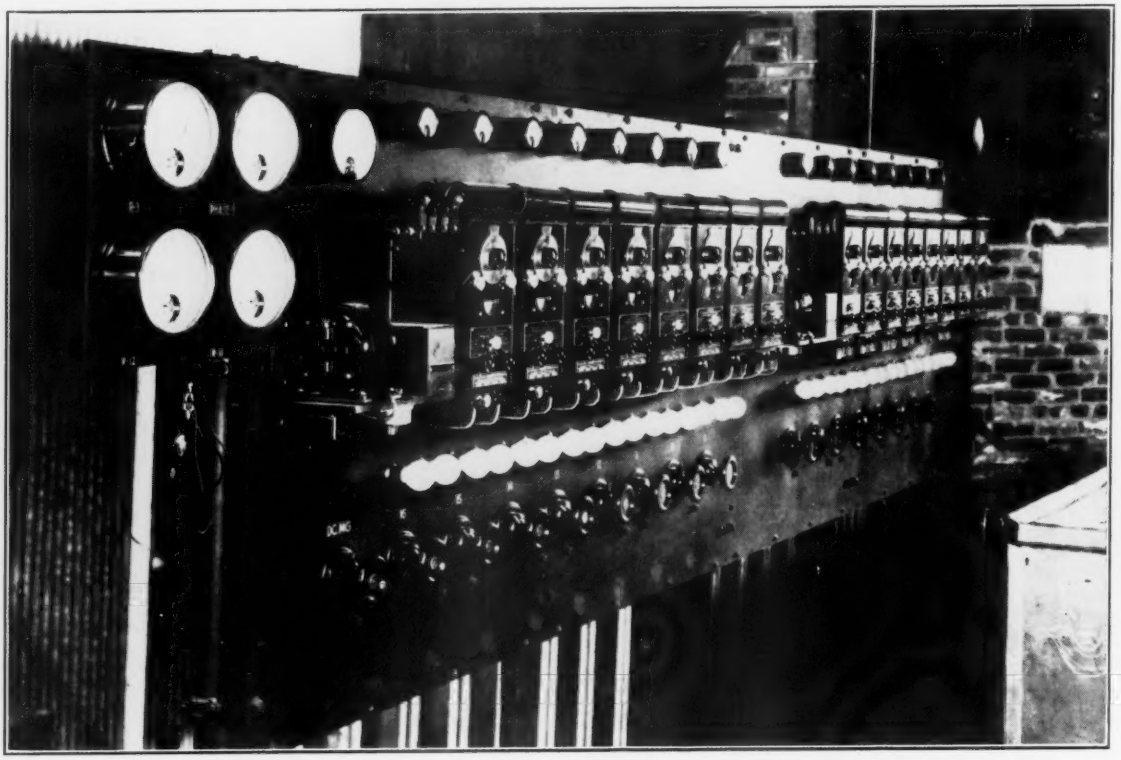

FIG. 10.—Group of automatic temperature controllers employed on the annealing kiln.

they may be set and read to one degree in the annealing range between 400°C and 550°C.

(4) Mold

(*a*) *Design.*—The construction of the mold (Fig. 11) of insulating brick represented something new in masonry. The $4^1/_2$-inch bottom and the outside wall of $11^1/_2$ inches presented no problems. The novel feature was contained in the 114 cores necessary to give to the disk the ribbed back which was desirable from the standpoint of decreasing weight without sacrificing rigidity. The design of the ribbed structure is formed by dividing the area of the disk into equilateral triangles with small irregular shapes remaining over at the rim. At the intersection of the ribs forming these triangles, circular ribs are introduced. These are to serve as points of support in mounting the disk in the telescope. It is evident therefore that the necessary cores to form the ribbed pattern would consist of cylinders and triangular prisms with a small number of irregular prisms at the outer rim.

These cores vary in height as it is desired to have the slab of glass over the cores of uniform thickness after the mirror is finished to a concave figure. Thus the cores decrease in height from 20 inches at the rim to 16 inches near the center. The construction of the cores had to be such that metal anchors could be applied to exert on every brick in the core a downward pressure to prevent the possible floating of the core either as a whole

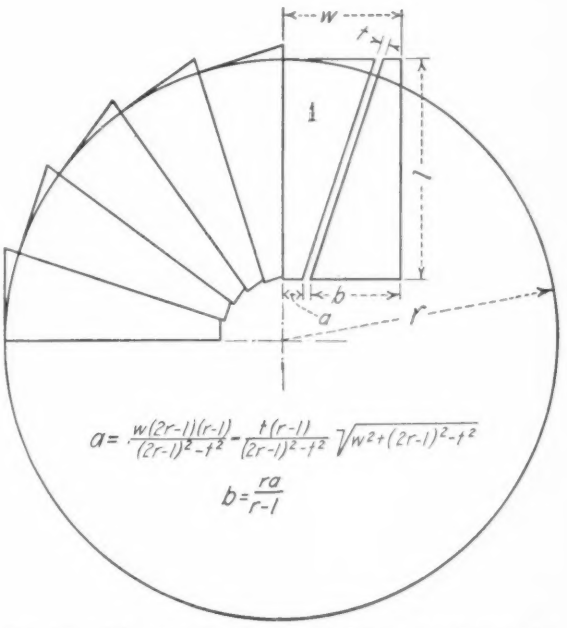

FIG. 12.—Diagram showing how brick were cut to make the circular cores used in the mold of the 200-inch disk.

or in part. It was also necessary to provide for adequate protection to these anchors against the heat encountered during the casting operation. These provisions were met by making the top course of brick in all cores nine inches thick and recessing the anchors. The hole over the top of the anchor was then filled with a suitable plug. Because of the multitude of brick shapes in the building of these cores, it was desirable to keep their numbers to a minimum so that the labor of

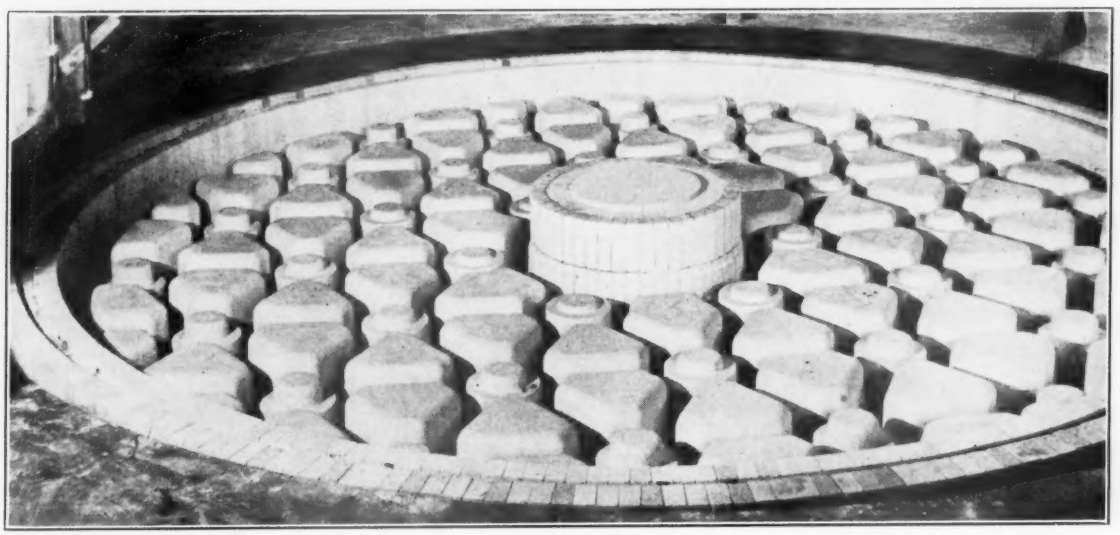

FIG. 11.—Assembled mold for the 200-inch disk showing the central core to produce a 40-inch hole used for a Cassegrain mounting.

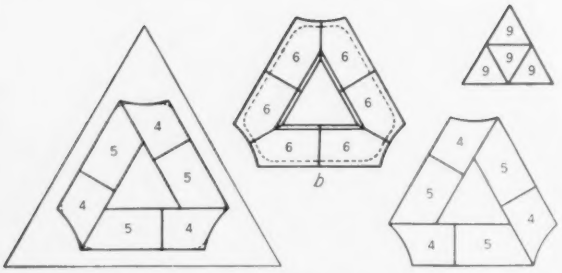

FIG. 13.—Diagram of brick shapes used in the cores of the 200-inch disk.

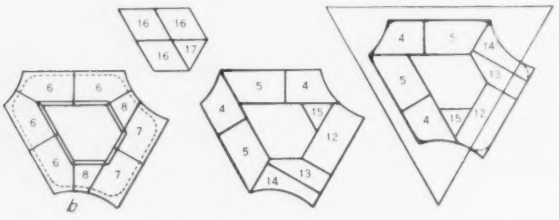

FIG. 14.—Diagram of brick shapes used in the cores of the 200-inch disk.

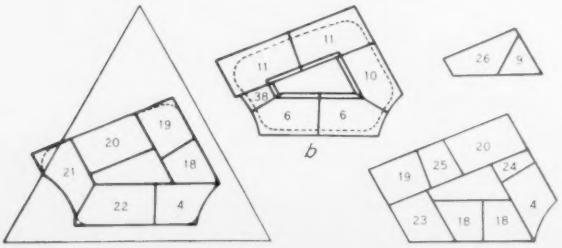

FIG. 15.—Diagram of brick shapes used in the cores of the 200-inch disk.

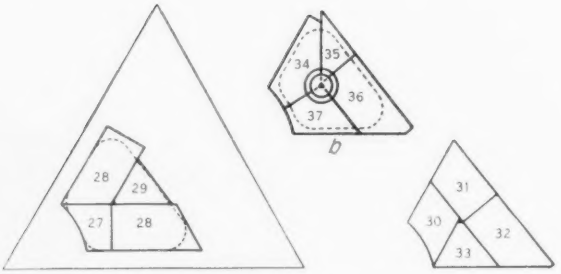

FIG. 16.—Diagram of brick shapes used in the cores of the 200-inch disk.

cutting and building might be reduced. To give strength against possible splitting, continuous vertical seams were to be avoided by overlapping the pieces in each horizontal layer. And finally it was considered essential to give some thought to the waste of brick material involved in cutting the pieces for the cores.

(*b*) *Fabrication.*—The proper shape, *l*, for the cylindrical cores (Fig. 12) was obviously a wedge. The application of a little algebra and plane geometry indicated along what line one must saw a standard 9-inch brick to produce two equal wedges, of sides *a* and *b*, for turning a circle of 11 inches outside diameter with a wall thickness of $4^1/_2$ inches. This gave for these cores 9-inch courses of which two and a fraction more or less sufficed and provided the requisite 9-inch course at the top in which to bed the anchor. For the

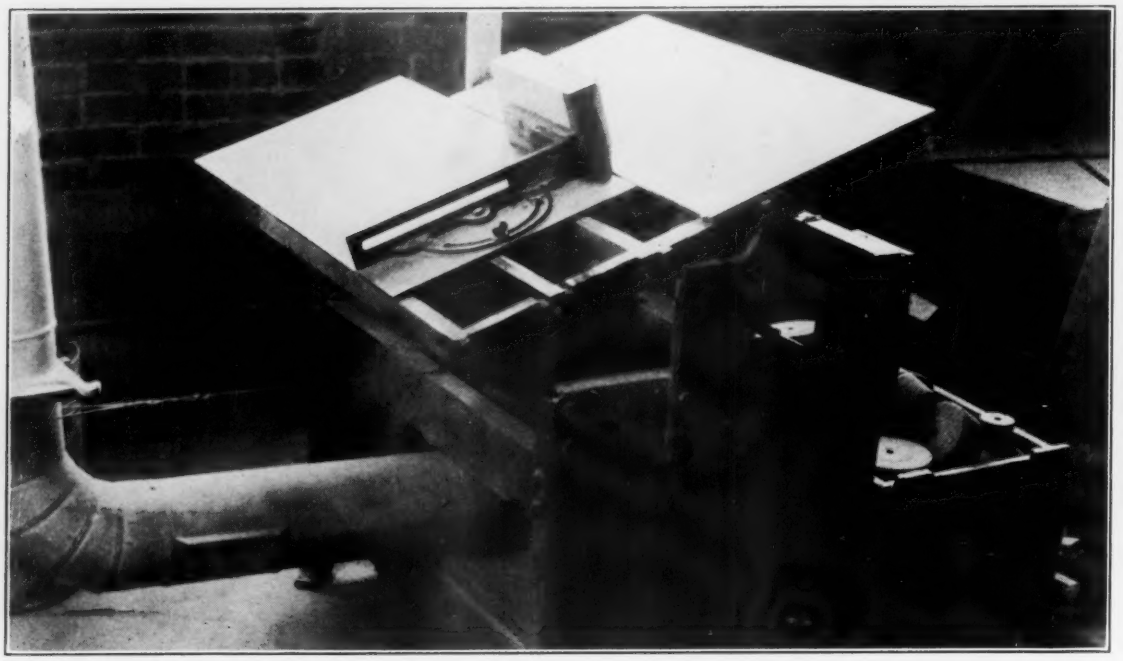

FIG. 17.—Tilting table saw illustrating the method of cutting brick shapes for use in the mold cores.

triangular prisms (Fig. 13), it was apparent that two shapes, 4 and 5, would suffice except for the 9-inch top course. One of these would possess the circular cut to conform to the circular rib while the other of straight-line pattern would fill out the remaining portion of each side of the triangle. By reversing these shapes in alternate layers all joints were overlapped. It was not possible to make the top course nine inches thick for these and the remaining cores from standard brick shapes. Special brick sizes, 9 by 9 by $4^1/_2$ inches, served from which the shapes, *b*, for these top courses were obtained. A triangular shape, 9, filled in the space over the anchors. Proper shapes (Figs. 14, 15, and 16) for the remaining cores were developed in the same way until all were provided. In all, 38 different forms were necessary from which approximately 4800 pieces were cut in order to make the 114 cores entering into the construction of the mold.

The actual cutting of the pieces for the cores was accomplished with an old table saw (Fig. 17) with tilting table fitted up to take a 14-inch Carborundum wheel, $^1/_8$ inch in thickness, and a vertical grinder (Fig. 18) of special design fabricated in the shops of the Corning Glass Works. Circular cuts, grooves, and rabbets were executed on the grinder by sliding the brick along a straight-edge guide past the wheel of proper thickness and

FIG. 18.—Vertical grinder illustrating the method of making circular cuts used on the mold cores.

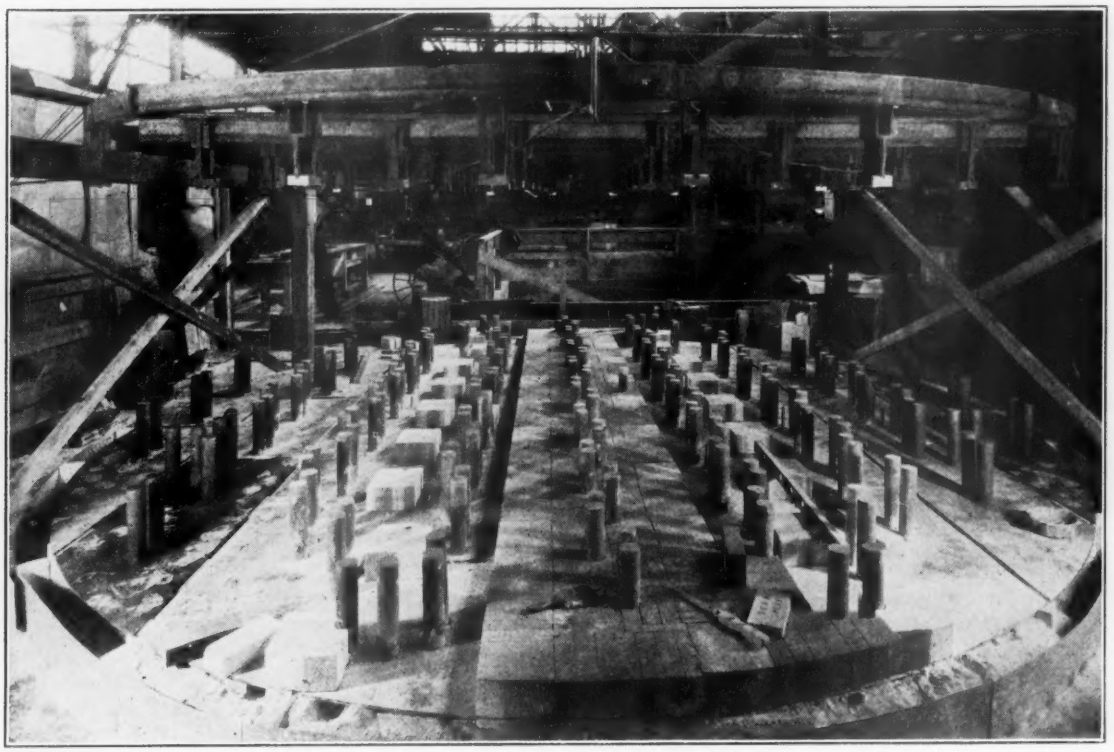

FIG. 19.—Lower part of annealing kiln in process of construction on the screw hoist. Mold frame of circular angle and parallel T-bars suspended from overhead before placing in position.

adjustment. For circular cuts, the table of the grinder is provided with a center of rotation that can be varied in distance from the cutting face of the wheel. With the proper setting of this center, circular cuts are made by setting the brick on the table against stops and rotating the table about the wheel. The proper setting for each machine is obtained by a wooden template of the piece to be cut. These templates were, of course, made full size in the pattern shop from previously executed drawings.

The cementing of the pieces to form the cores and the subsequent rubbing of the surfaces of all except those of cylindrical form to the proper taper with the aid of wooden templates, clamped top and bottom, offered no engineering problems but rather called for skill on the part of the masons. This was admirably shown in the fine work done. Likewise the painting of the cores with the aid of a paint brush to apply the required silica flour coating needs no further mention.

To eliminate some of the grinding required inside the circular ribs of the disk where its proposed supports were to be fixed, part of the groove needed was to be formed by a cylindrical boss on the core. Thus the shaping of these cores was found to be most easily accomplished with the aid of a grinding wheel attached to the tool carriage of a lathe equipped with a taper attachment. In the absence of the grinding wheel at the time the first cores were needed, a common cutting tool for steel was employed.

(*c*) *Assembly.*—The assembly of the mold on the table top of the screw hoist presented several problems. In the first place, a steel frame (Fig. 19) was needed that would not only support

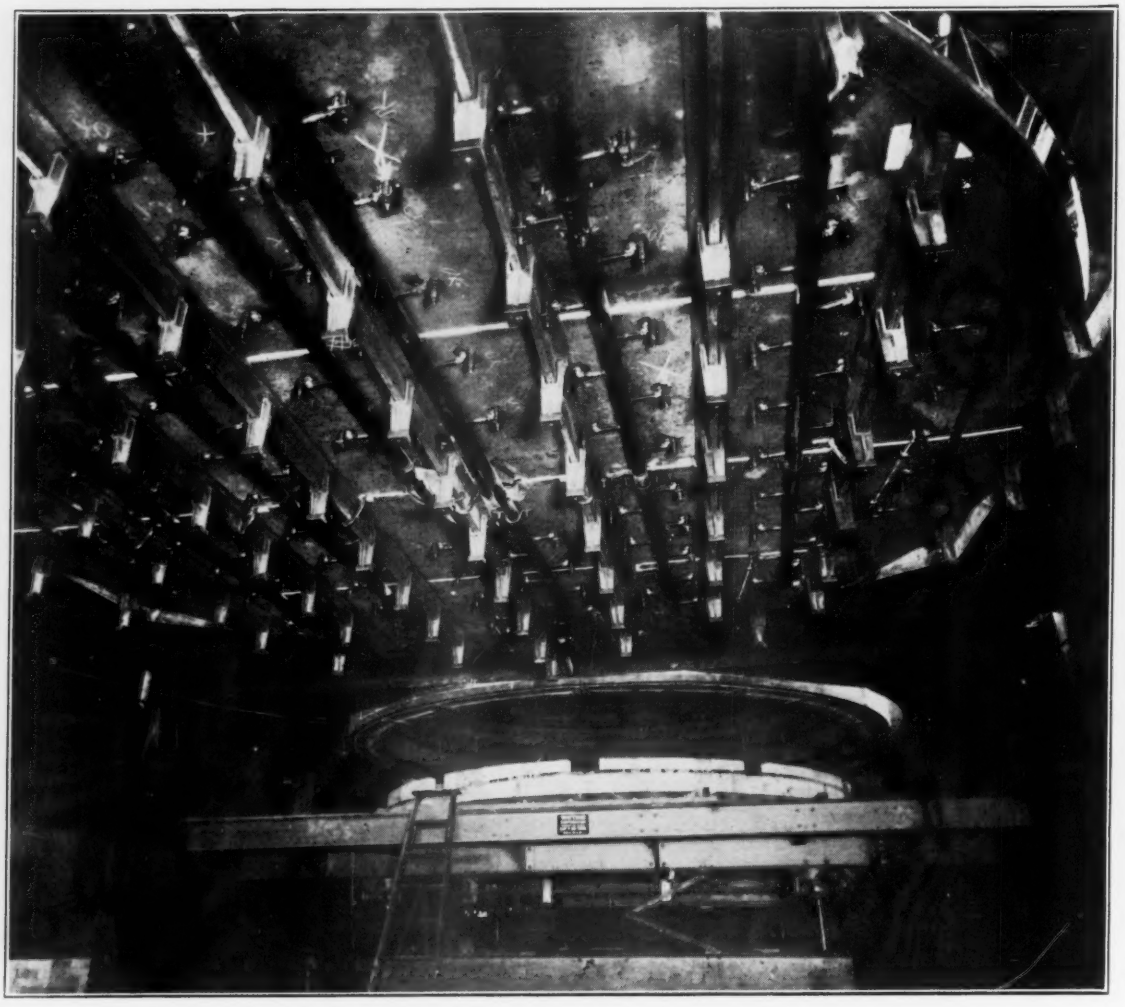

FIG. 20.—Under side of mold frame showing the system of pipes used for cooling the mold core anchors.

(without sagging) the mold and disk while casting and annealing but must be capable of lifting the disk from the hoist for finishing and crating. This frame is built of T-bars framed in an angle bent to a circle approximately two feet larger in diameter than the glass disk itself. On the T-bars rest the iron plates on which the mold bottom is laid. Two small pins in the T-bars, fitting into holes in one edge of the plates, prevent the latter from sliding out of place and permit free expansion. Fastened to the under side of these plates are the pipes (Fig. 20) which constitute the manifolds of the cooling system for the anchors to the cores. These anchors of heat-resisting alloy, known as Calite B-28 from the Calorizing Company of America in Pittsburgh, are subjected to a maximum tension of approximately 250 pounds by the buoyant force of the molten glass. Preliminary experimental tests had shown that when loaded to this extent these anchors could be safely held at a temperature of 830°C for a period of two weeks and had resulted in a measurement of the quantity of cooling air that was required to maintain them at this temperature while the furnace in which the core was located was held at the maximum temperature used in casting the disk. In the cooling of these anchors, air is used instead of water to avoid the difficulty that would arise if, owing to a leak, the cooling fluid entered the region below the mold containing the leads of the electrical heating elements whose insulation from one another depends upon the dryness of the brick and powder used in this part of the construction. Suitable pressure gages, manometers, and control valves for this cooling system are mounted on a panel where the operation can be closely watched for any deviation in the necessary flow of air previously determined. As a further check on the system, thermocouples in certain representative cores register the temperatures at these points and serve as an index to tell when more or less air is needed.

IV. Melting Tank

With preparations completed to receive the glass in its mold and to anneal it, attention was once more given to the melting equipment. To add capacity to the tank, the usual bridge wall was removed. This provided an extra holding capacity of approximately seven tons, lessened the refractory lining requirements, and eliminated refractory area from which cordy glass is apt to arise together with the throat whose effect on quality when glass is drawn rapidly is still unknown. For inserting the ladles, suitable openings (Fig. 21) are provided and are fitted with counterweighted doors operated vertically by means of a cable and drum and cooled with low-pressure air.

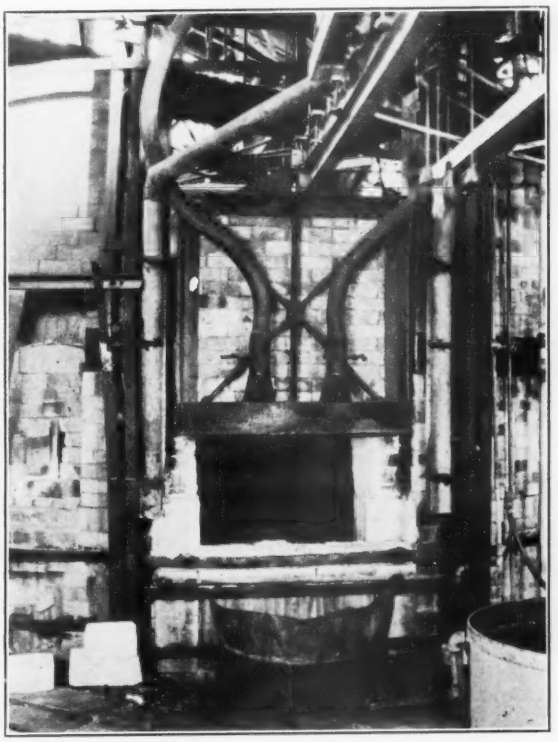

FIG. 21.—Ladling door of the tank showing the removable flux wall, the cullet hopper, and the ladle cooling vat at the extreme lower right.

The removal of the bridge wall was not sufficient to overcome completely the difficulty of a tank somewhat too small for the purpose. Other steps were necessary to correct for a change of level of 15 inches which the withdrawal of at least 30 tons of glass would produce. Filling the tank with raw batch while ladling was out of the question because of the very slow rate at which it is possible to melt and fine this glass. It was feasible, however, to consider the replacement of the ladle skins, hot from the ladles, in the filling end of the tank. If this were done, a level change of only 10 inches would be expected. Provision for this was made by building the top 12 inches of the tank wall directly beneath the ladle openings of three courses 4 inches thick. To facilitate the removal of these one after the other as the glass level drops,

each is held in place by a separate iron strap fastened to the steel of the tank and easily removed with a torch. As a further aid in the removal of these refractory slabs, each layer consists of three pieces so bevelled that the center one is narrower on its inner face against the glass than at the outside. The center piece is thus readily loosened; and with this piece, or wedge, out of the way, the end sections of the same course are easily removed.

V. Ladling Equipment and Practice

With provisions made for ladling the glass at lower levels, means now had to be perfected for lowering the ladles as they were being filled. This could be done to some extent by lengthening the hangers (Fig. 22) of the ladles with the turn-

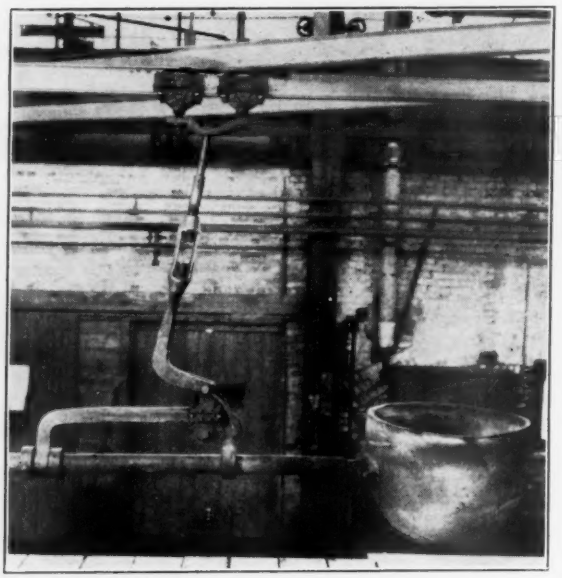

FIG. 22.—Suspended ladle of 750 pounds capacity, showing the usual hanger and trolley.

buckles with which these are equipped. It is not desirable, however, to depend on this adjustment for too much of the anticipated drop in level, as it is essential to keep the distance from ladle to top of mold during pouring as small as possible to avoid the excessive formation of blisters in the disk. Accordingly, a small cushioned water cylinder, supplied by the Hanna Engineering Company of Chicago, is installed over each ladle track near the tank. With this cylinder, a short section of track is raised and lowered by definite steps. To complete the accommodations for a change in glass level then, it is only necessary to lower the remaining section of track near the tank a given amount and set the cylinder to operate in this interval. The empty ladles are thus lowered for filling and the full ladles raised for transference to the mold and pouring. The distance of the lift cylinder from the tank is just sufficient to permit the closing of the furnace door after the ladle is withdrawn. By locating the lift at this point where the excess glass is cleaned from the ladle on emerging from the tank, no time is lost for the operation of the lift, as this operation and the cleaning of the rim of the ladle proceed at the same time.

The only remaining problems now in connection with the actual casting of the disk are those of moving the ladle skin from the ladles to the filling door of the tank, cooling the ladles, and

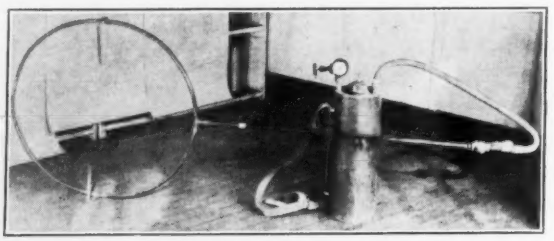

FIG. 23.—Ladle cooling spray for cooling the outside of filled ladles.

disposal of any ladles of glass of objectionable quality. For the latter purpose hoppers, also shown in Fig. 21, are placed immediately outside the tank beneath the ladle openings. Into these the ladles can be dumped if desirable and the skimmings from the tank disposed of. Alongside, are large vats of cold water built into the floor, in which the ladles are cooled before entering the tank. Because of the long haul from tank to mold, the high temperature of the glass, and the presence of a heated atmosphere surrounding the ladles while pouring in the mold, it is necessary to apply cooling to the exterior of the ladles directly after filling while on their way to the mold to prevent them from reaching the scaling temperature. This is done with a hand-manipulated compressed-air water spray (Fig. 23). An automobile tire-valve stem and air-hose connection with a high-pressure air system makes charging with air simple. The water supply is through a fitting provided with a stopcock. Water from this spray, circular in shape and resting on the top of the ladle, strikes the outside of the ladle

rim and flows down its outer surface. Some water, of course, finds its way into the ladle but does no harm as it quickly evaporates.

The transfer of ladle skins from the ladles into the filling door of the tank is relatively simple. Fortunately the regular filling shovel used for feeding batch to the tank is large enough to accommodate one of the skins. Hence it is only necessary to get them into this shovel which is approximately five feet above the level of the ladling floor. The least expensive and most easily installed equipment for this purpose seemed to be a hand-operated wheel barrow to service each ladle. These are equipped with high backs to protect the operator from the radiation of the hot glass and two wheels to make the work of balancing an off-centered load less difficult, though the principles of steering are thereby

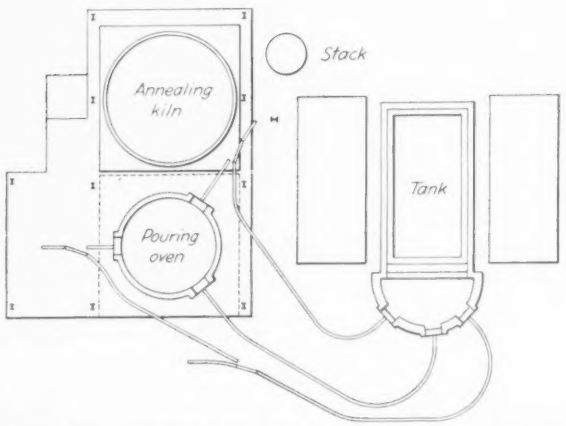

FIG. 24.—Diagram showing the relative positions of tank, pouring oven, and annealing kiln together with the ladle track system.

altered. A ramp suffices to raise the wheel barrows to the proper elevation for dumping the skins into the filling shovel. The work of moving the loaded barrows up the ramp is performed with the assistance of two additional workmen who catch the frame of the barrow at each side with suitable hooks and assist the man at the handles.

No mention has been made of the problem of getting ladles or of conducting tracks (Fig. 24) for these ladles from the ladling doors of the tank to the pouring doors of the oven over the mold. This latter feat was merely one of dodging columns, pipes, kilns, and even the stack of the tank by the judicious use of curves and switches. The result is that one of the three ladles can be turned after filling at the tank and pushed forward to the pouring oven. The other two must be pulled backward past the mold and switched to a siding before entering the door of the pouring oven.

In the matter of ladles of suitable size and weight of material, the problem might have been serious had it not been for the fact that the McClintic Marshall Company of Buffalo, N. Y., had retained the old dies with which they formerly pressed ladles for the American Window Glass Company. Larger ladles than these of 750-pound capacity were considered too large for hand operation and smaller ones were undesirable, as the more ladlesful of glass required to make an object, the greater the number of blisters introduced. While it was possible to secure ladles of this size, now obsolete equipment, from the American Window Glass Company, they were too thin for the high temperatures involved. Accordingly, at the suggestion of William Monro, Jr., of the American Window Glass Company, the McClintic Marshall Company was consulted as a probable place to duplicate these ladles in size but of heavier metal. Within eighteen days from the placement of the order for three of these ladles they were in the shop in Corning to be fitted with handles.

VI. Annealing

In the beginning of this work, no problems were thought to exist in connection with annealing. It was believed that the customary procedure outlined by Adams and Williamson[1] could be followed with assured success. Accordingly, rates of release of stress for the glass to be used were measured by H. R. Lillie at Corning and by G. W. Morey at the Geophysical Laboratory. The results from these two sources verified those of Adams and Williamson obtained at low temperatures, *viz.*, that the rate of release of stress at a fixed temperature is not proportional to the square of the stress except possibly after very long intervals of time when, as observed from data supplied by Lillie, equally good agreement was found between computed and observed values, if the rate of release of stress were assumed to be proportional to the first power of the stress. Moreover, the slope of the logarithm of the

[1] L. H. Adams and E. D. Williamson, "The Annealing of Glass," *Jour. Franklin Inst.*, **190**, 597–631, 835–70 (1920).

annealing constant-temperature curve obtained from rates of release of stress at low temperatures after long periods of time was found to be the negative slope of the logarithm of the viscosity-temperature curve. Other data by Lillie[2] showed that the viscosity of a chilled sample of glass increased with time when held at a temperature below that from which the chilling occurred. The conclusions from these observations were that the annealing constant of the glass was proportional to its mobility and that both these properties were definitely determined by temperature if only time enough were allowed for the glass to arrive at an equilibrium state at the given temperature. The direct result of these discoveries

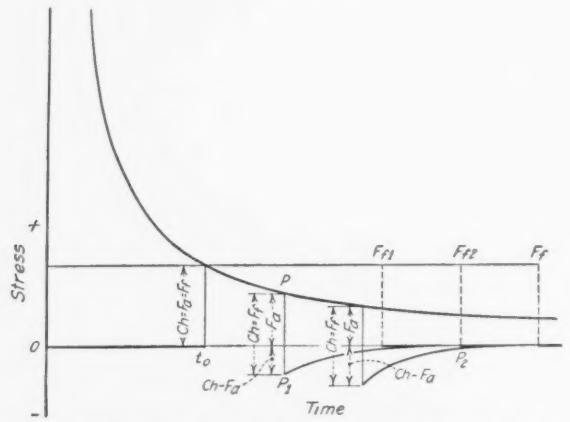

FIG. 25.—Diagram illustrating the theory of annealing to a prescribed degree of stress.

was the elimination from the annealing process of any variable rate of cooling. Such a procedure implies a knowledge of the exact value of the annealing constant at each instant during the cooling process. Obviously such knowledge does not exist, if mobility is changing with time after any change of temperature from an equilibrium state.

The adopted procedure of annealing then became quite simple. There was employed only the fundamental concept that the final stress in glass is the numerical sum of that remaining when cooling begins and that released during cooling and that, if a constant cooling rate be applied, the stress released on cooling can be no greater than that introduced by this rate. The application of this to annealing to any given degree is perhaps best illustrated by referring to Fig. 25, where stresses are plotted as a function of time. While holding at constant temperature, the initial stress in the glass falls off along some curve as shown until it arrives at a value, F_a, after a time, T_a. If this value, F_a, be allowed to become equal to or less than the final value, F_f, which is desired in the cold glass, then this final value, F_f, may be obtained by imposing a constant cooling rate, h, such that $ch = F_f$, where c is a constant determined by the expansion, the diffusivity, and the elastic constants of the glass together with the thickness of the article being annealed. Thus, assume the glass to be held at constant temperature until the stress drops to the value at point P. This stress, F_a, called the "residual" stress by Adams and Williamson, will be a compression in the outer fibers of a glass slab whose stress is the result of cooling from the fluid state. If a stress, $ch = F_f$, be introduced now by a cooling rate, h, the actual resultant stress in the glass will be a tension, $ch - F_a$, represented by point P_1. As cooling proceeds, this "temporary" stress may all be lost as indicated by the stress curve from P_1 to P_2. Since there is now no temporary stress remaining, no further stress can be lost as cooling continues. Hence, from the fundamental relation stated above, the total magnitude of the final stress can be no greater than $F_a + ch - F_a$, or ch, which was chosen equal to F_f. It is seen also that it makes no difference from what point, P, on the stress-time curve one starts cooling as long as it is after the time, t_0, when the stress has reached the value, F_f, and provided the cooling rate is so chosen as to yield a stress numerically equal to the final value, F_f. Thus the total time of annealing would be shortened if the soaking period were ended at time, t_0, when the residual stress, F_a, reached the numerical value of the final stress; but as the computation of this time is dependent on a still unknown law of release of stress, it is safer to soak longer. By this method of annealing, soaking periods are much shorter than those of cooling.

The soaking temperature for which the total time of annealing will be least is determined graphically. A curve, a (Fig. 26), is plotted from the relation, $t_a = \dfrac{1}{F_a A_a}$, which defines the soaking time at a given temperature in terms of the residual stress, F_a, which may be any value

[2] H. R. Lillie, "Viscosity-Time-Temperature Relations in Glass at Annealing Temperatures," *Jour. Amer. Ceram. Soc.*, **16** [12] 619–31 (1933).

less than the final desired stress, F_f, and the annealing constant, A_a, for the particular soaking temperature. Another curve, b, is computed from the relation, $h = \frac{F_f}{c}$, which connects the cooling rate, h, with the final stress, F_f, and the constant, c, involving the expansion, diffusivity, and elasticity of the glass and the thickness of the article. Obviously, since only constant cooling rates are employed, this latter curve when plotted with the coördinates of temperature and time is a straight line. With these two curves (a and b) plotted, the temperature at which they have the same slope is the one for which the total annealing time will be the shortest. Thus for a piece of glass whose thickness requires a cooling rate given by curve b, it would be possible to produce the same degree of annealing by soaking at temperatures θ_1 or θ_2 and cooling along curve c; but the total time in either case would be greater than if soaking were done at θ_3 and cooling proceeded along curve b.

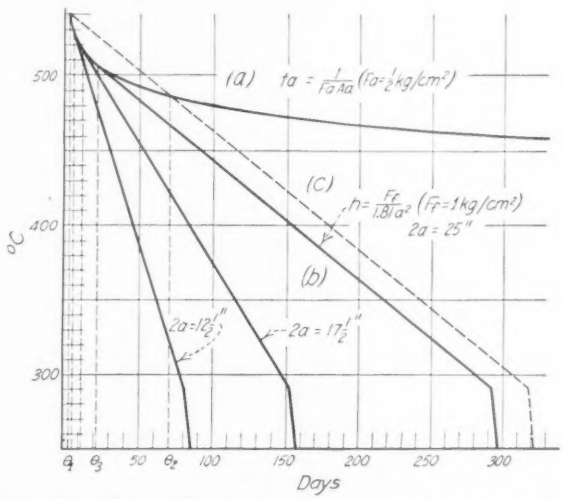

FIG. 26.—Curves illustrating the computation of annealing schedules employing the least total time.

Actual attainment of the temperature-time cycle in the annealing of the disk is accomplished by means of combined automatic and hand operation of the temperature controllers. During the period of soaking, full automatic regulation keeps the temperature at the desired value. When cooling begins, however, the controllers are set by hand to give the desired rate of cooling. Thus for the cooling of the 200-inch disk which must be lowered 0.8°C per day to insure a degree of annealing of approximately 5 mμ per centimeter, the ten controllers are set one after the other at intervals of three hours to operate one degree lower. This is easily done with the circular scale and vernier attachment. A day's labor may seem a high price to pay for setting eight controllers at three-hour intervals. On the other hand, for a venture of this kind, the constant attendant is relatively inexpensive insurance against possible failures to electric circuits and power-supply systems.

VII. Removal from Conveyance

To provide for lifting the disk after annealing from its bed on the screw hoist, a separate building was required. This is located directly in line with the casting and annealing positions so that an extension of its track enables the screw hoist with the disk to be transferred to the new location where space is available for standing the disk on edge and for inspecting and cleaning. In this location, all further operations pertaining to crating and shipping can be accomplished without interruption to the routine operation of the plant.

The removal of the disk from the screw hoist is accomplished in the following manner. The outside rim of the mold is removed and two large I-beams are fastened with U-bolts to the mold frame so as to catch the ends of as many of the parallel T-bars of this frame as possible (Fig. 27). The hole in the center of the disk, in this instance, permits a tie also between the center of the mold frame and I-beams above through the use of two other beams at right angles to the first pair and passing over the center of the disk. Four large hand-operated chain hoists of sufficient capacity to lift nine tons each and hung from overhead beams, carried by columns independent of the building, provide means for lifting the load free of the screw hoist. Connections for the hooks of two of the hoists are made directly with the two ends of one of the large I-beams attached to the mold frame. Connection to the other I-beam is made at its mid-point to a second parallel beam to the ends of which are attached the hooks for the other two hoists. This arrangement provides a three-point suspension for the load and insures nearly equal distribution of the load on all four hoists without danger of overloading any one to the breaking point. To save man power, the disk is first raised by the screw hoist and the hand hoists set with

chains taut. The screw hoist is then lowered leaving the disk suspended and the screw hoist clear without the expenditure of manual labor.

The next problem is to remove the core-anchor cooling system, the iron plates resting on top of the mold frame bars and supporting the base of the mold, and lastly the mold frame itself. As the safety of the workmen is always the first consideration, the load is supported on shoring from beneath and removed from the hoist chains above. For this purpose, a heavy timber structure is built up from the screw hoist rails below and supports a working platform of three-inch planking. Blocks between this platform and the legs

FIG. 27.—Chain hoists lifting the 200-inch disk from the screw hoist conveyer.

of the mold frame hold the disk safely in the clear while workmen remove the system of core-anchor cooling pipes and release the connections of core anchors from the bottom plates. The load is again lifted and the blocks placed beneath alternate rows of plates of the mold bottom. As the load is now lowered, the entire mold frame and the bottom plates, not supported by the blocks, fall to the floor. With these loose plates come also the brick of the mold bottom directly over them. After clearing away these plates and loose brick, a set of four I-beams is placed beneath the disk in positions to engage its bottom in the places previously exposed by the removal of plates and bottom brick. The system of lifting beams to which the chain hoists are attached are disconnected from the mold frame and bolted to this last set of four beams under the mold (Fig. 28). Raising the mold on these beams now liberates the remaining plates and mold bottom together with the mold frame which is removed on rollers and replaced on the screw hoist.

VIII. Crate Design

The remaining problems to be considered are removing the cores and cleaning the surface of the disk, inspecting for strain, crating, and loading. As all of these except crating involve standing the disk on edge with the attendant provision for some form of grip with which to accomplish this, it is only natural to design this grip as the crate itself, part of which may be removed with the disk in the vertical position for extraction of cores and inspection. This crate

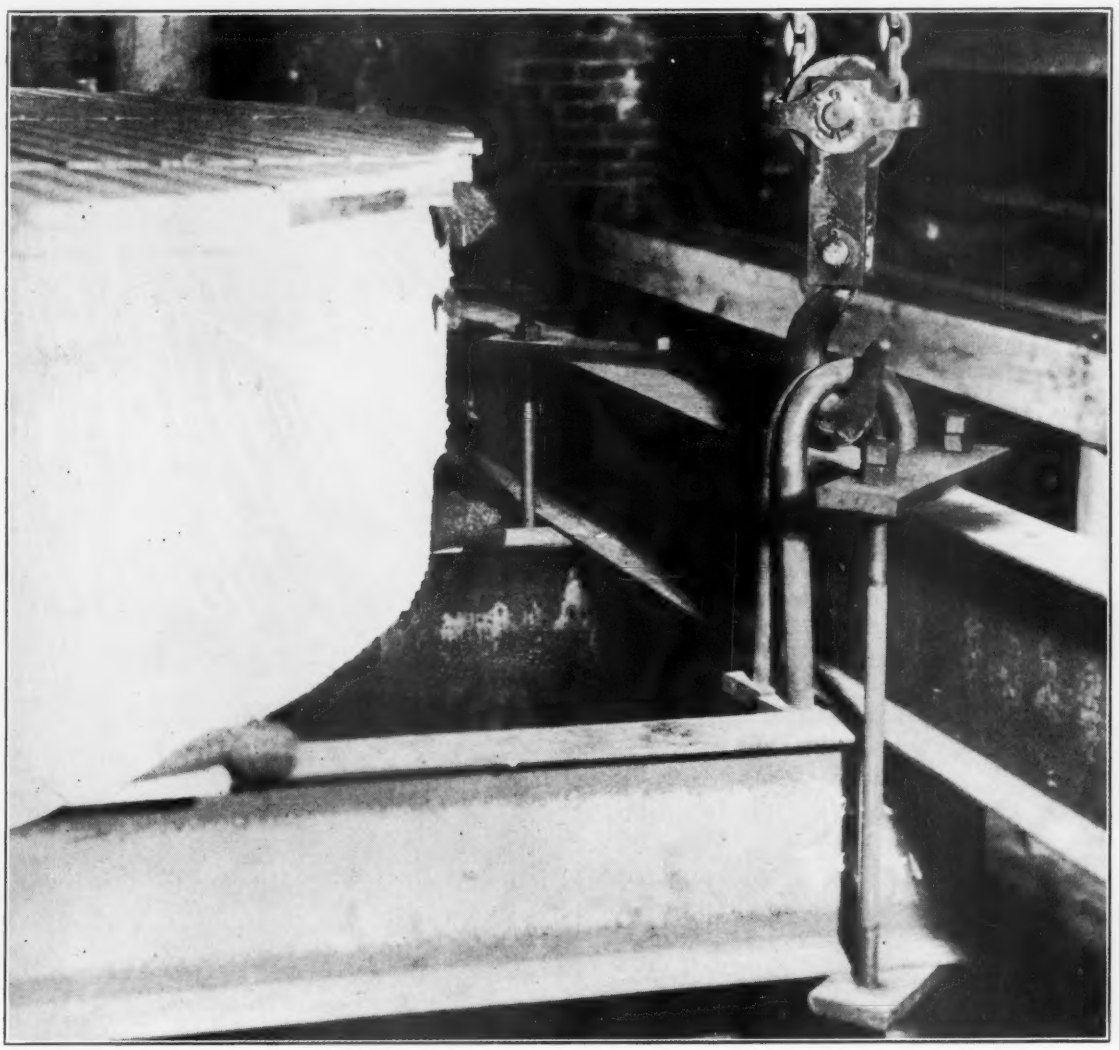

FIG. 28.—Screw hoist hitch used in removing the mold frame from beneath the disk.

must provide for an adequate cushion, or pad, between the glass and the steel of the crate. While glass is very strong in compression, it is also quite brittle, and contacts with hard substances must be avoided if all danger of chipping the glass is to be prevented. The crate must be built up of sections if the sides covering the two faces of the disk are to be removable for inspection and other needs. It must have an overall height less than 17 feet and 3 inches for existing railroad clearances; and finally the crate must carry its load with only stresses of compression in the glass. It is proposed to meet all these requirements by a structural steel container (Fig. 29) consisting of four identical quadrants, *ABC*, which, when bolted together, will form a square carton with a circular cavity for containing the disk. The

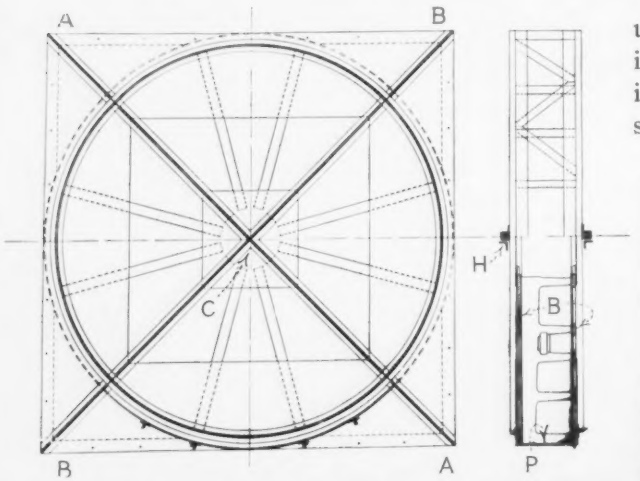

FIG. 29.—Proposed crate for shipping the 200-inch disk.

strength of each quadrant or truss is sufficient for supporting the disk on edge, but the whole assembly is needed in the process of placing it in this position. In each quadrant the central sectors are removable; so that with the disk on edge its two faces may be entirely accessible. With this part of the crate removed, the disk is in effect enclosed in a band having a circular inside and a square outside contour. To keep dimensions within the prescribed limits the pad, *P*, for the space between the circular band of the crate and the disk consists of a layer of felt one inch thick compressed to half this thickness by the bolts of the crate. On the sides of the disk, where more area is available for bearing surface on the padding and where railway clearances do not restrict, a less expensive and weaker pad in the form of slabs of cork board, *B*, three inches thick are used. These, too, are compressed to approximately $2^1/_4$ inches as the bolts of the crate are drawn tight.

IX. Finishing and Inspecting

Removing the cores from the ribs of the disk and cleaning its surface is accomplished with a sharp-edged bar and a sandblast and presents no great problem; except, of course, great care must be exercised, if a bar is used, that the glass be not struck too severely. Removing the cores with a bar must be classed more as work than as a problem. The sandblast works slower, with more dust, but easier, and is ideal for cleaning the entire surface that has been in contact with the mold.

While inspection for strain is made with the usual polariscope, consisting of two crossed-nicols in conjunction with a quartz-wedge compensator, it is necessary to provide means for holding the separate parts of this equipment on the two sides

FIG. 30.—Wrecking crane loading the 120-inch disk on "well" car.

of the disk so that measurements of strain can be easily and quickly made from point to point over its entire surface. For this purpose, a pair of standards or guide posts is fastened to each face of the crate near its edge. These guides carry the ends of a horizontal straight rail along which slide the polarizer and lamp on one side

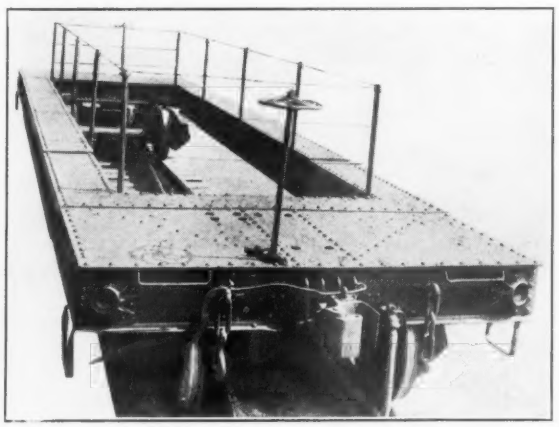

FIG. 31.—"Well-hole" car on which it is proposed to ship the 200-inch disk.

and analyzer and quartz wedge on the other. In this way all points of the disk are easily reached for measurement of strain in the direction of the axis of the disk. Readings through sections

FIG. 32.—Crate employed for the 120-inch disk, illustrating the principle of double crating proposed for the 200-inch disk.

of the ribs are made by manipulating the component parts of the polariscope by hand at the point under observation.

X. Loading

Loading the disk for transportation will be accomplished either by a construction- or railway-wrecking crane (Fig. 30), both of which are available. A special type of car (Fig. 31), known as a "well-hole" car, will be used. In this type there is no platform between trucks. The load is carried on side girders and hangs nearly to the rails below. On these side girders and rigid with the car will be built a second crate of structural steel into which will be set the one containing the disk. Between the two crates, at bottom, ends, and sides, cork and felt under compression will be employed to take the thrusts. In principle, though not in detail of construction, this is the same as used for the 120-inch disk (Fig. 32) which has been successfully shipped and is now in the process of finishing.

XI. Conclusion

With this account of the problems connected with the manufacture of a 200-inch disk and of the methods employed to solve them, may it be stated once more that these engineering practices are not offered as the best ones to be used in making large telescope disks. No doubt these would be changed in many details were equipment being set up to make large quantities of disks for years to come or even to make a single large one in a new location that had no useful assets in the form of furnaces, kilns, or other equipment. The methods here described are simply those that served the purpose and could be fitted easily into available building space and coördinated with existing equipment with a minimum of expense. They are presented merely as a historical record of the manufacture of a piece of glass which, it is hoped, may become, through its usefulness in scientific research, a priceless heritage to future generations.

Acknowledgment

In conclusion, may I be allowed to express my own personal thanks and appreciation to the firm that employs me and to the many men in it for the assistance afforded me in the fulfillment of this task. To the Corning Glass Works, I am greatly indebted for the confidence and trust placed in me. May I express here to the executives of the Company through its President, Amory Houghton, my sincere thanks. To J. C. Hostetter, Director of Research

and Development, I am indebted for the assignment which gave me the responsibility and authority to see the work through, and I desire to express my thanks for his unfailing support day after day. To J. T. Littleton and W. C. Taylor, thanks are due for the facilities of the Physical and Chemical Laboratories, especially of the assistance of H. R. Lillie for measurements of annealing constants, of W. L. Wetmore for measurements of other physical properties of the glass used for control of melting, of W. W. Shaver for assistance in strain measurements, of H. P. Hood for the very remarkable glass composition, of M. E. Nordberg for measurements of chemical stability, and of R. D. Smith and men in his charge for analyses of material. To W. Wood and R. Newman, I am grateful for the help given in carrying out the experimental work involved in ladling and mold construction. To the foremen and men of the Engineering Department and Trades, I owe the realization of all the many ideas put forth to solve the problems presented here. To these men too numerous to give individual mention, for their patience and untiring efforts, and for their fine workmanship, I am deeply indebted. To the men of the Mixing and Melting Departments, I wish to state my appreciation for the careful manner in which the glass was prepared. To the Purchasing Department and to the firms with whom they dealt, I am grateful for the excellent deliveries and quality of products secured. To the men at the ladles and to those who assisted them in the long arduous task of forming a 200-inch glass disk, I express my appreciation for their willing and determined efforts to succeed and for the fine work accomplished. I wish also to acknowledge the assistance of G. W. Morey of the Geophysical Laboratory for his measurements of annealing constants and of A. L. Day, Director of the Geophysical Laboratory, for his advice and counsel. To G. E. Hale of Mt. Wilson Observatory and California Institute of Technology and to Max Mason, President of the Rockefeller Foundation, I wish to convey my thanks for the faith they placed in the Corning Glass Works and for the fine spirit of coöperation displayed all through the work. And to my many personal friends and those of the Corning Glass Works who have watched and waited, hoped, and even prayed for the success of the undertaking, I wish to acknowledge their really helpful interest.

Corning Glass Works
Corning, New York

ACTIVITIES OF THE SOCIETY

MEMBERSHIP ESSENTIAL AID IN COÖPERATIVE RESEARCH

By J. M. McKinley

Prior to 1900, most technical advances in industry were made by lone-handed experimenters. In that year, however, Willis R. Whitney began research in a corner of one of the buildings of the General Electric Company, Schenectady, N. Y. Organized industrial research was begun. Soon other companies began similar activities.

In 1901, the National Bureau of Standards was established on its present basis with organized research as part of its activities. In 1902, du Pont Company's pioneer research laboratory was established. In 1904, Bell Telephone's laboratory was under way. Then over a period of more than a decade came the laboratories of General Motors in 1910, of Eastman Kodak Company in 1913, and of Westinghouse Electric and Manufacturing Company in 1917.

American Ceramic Society Organized

In 1899, one year *before* the first of the above laboratories was established, the American Ceramic Society was organized to obtain coöperation in ceramic research. Since 1899, over 1600 industrial laboratories have been established.

The American Ceramic Society was established because lone-handed experimenting in ceramics was no longer productive of progress. The urgent need for organized cooperation is more evident today than it was in 1899 and becomes increasingly so with each passing year.

Publications of the Society

Although the publications of the American Ceramic Society are but one of its many valuable functions, they are invaluable aids to the research worker in ceramics. (1) *The Journal* of original research reports, (2) *Abstracts* of world-wide ceramic literature, and (3) *The Bulletin* dealing with applied research and research activities are the three publications issued every month.

This Society has organized collaboration of technologists from the clay, glass, and porcelain enamel industries, developing and applying the technology that is common to all. The aim and chief result of this vital activity of the Society is to establish an economical means of producing ceramic ware of superior quality.

1012 National City Bank Building
Cleveland, Ohio

173 MORE NOW THAN A YEAR AGO ARE COÖPERATING TOGETHER

	July 23, 1935	August 22, 1935
Paid in full		
Personal	1185	1194
Corporation	184	186
Honorary, Life, and Complimentary	27	26
Deferred personal	45	45
Part-payment personal	75	69
Subscribers	423	435
Advertisers	35	34
Current Sales	200	200
Total Circulation	2174	2189

ART DIVISION SUMMER MEETING DATE CHANGED TO OCTOBER 25 AND 26

Meetings Scheduled for Friday and Saturday at Syracuse, N. Y.

Definite plans have been announced for the Art Division Summer Meeting to be held at Syracuse, N. Y., October 25 and 26, 1935.

In all previous announcements this meeting was scheduled for Monday and Tuesday, October 28 and 29. This change in dates to Friday and Saturday of the preceding week, October 25 and 26, should be noted.

In addition to the five topics previously announced for discussion (see *The Bulletin*, p. 269, August, 1935), there will be a discussion on the following topic: (6) Relation of the Art Division of the American Ceramic Society to Craftsman Pottery Activities.

Dean M. E. Holmes, New York State College of Ceramics, Alfred, N. Y., will lead the discussion "Ceramic Art in Colleges."

Clifford H. Parmelee, Onondaga Pottery Co., Syracuse, N. Y., will lead the discussion on "Studio Kilns."

The Fourth Annual Robineau Memorial Ceramic Exhibition will be held from October 15 to November 11 in the Syracuse Museum of Fine Arts. (For details of this exhibition see *The Bulletin*, p. 269, August, 1935.)

Adelaide Alsop Robineau was a scholar and a creator. Her work was distinguished for its excellent craftsmanship, ceramic technology, and for the originality with which pieces of infinite detail were painstakingly completed. See *The Bulletin*, pp. 121–24, May, 1929, for details of her life history as a creative ceramist.

REFRACTORIES DIVISION SUMMER MEETING PROGRAM

Abstracts of papers to be presented at the technical sessions of the Refractories Division of the American Ceramic Society to be held September 20 and 21, 1935, at the Centre Hills Country Club, State College, Pa., have been announced by H. M. Kraner, Publicity Chairman for the Meeting.

It is hoped to start the technical session promptly at 2 o'clock, and it is requested that those who expect to attend this session will also attend the luncheon which will be held at 12:30 P.M.

Reservations for this luncheon should be made through Nelson W. Taylor, Penn State College, State College, Pa. For further details of the two-day program, see *The Bulletin*, pp. 269–70, August, 1935.

TITLES AND ABSTRACTS

(1) Experiences in the Use of Refractories in the Steel Plant

By Louis A. Smith, Jones & Laughlin Steel Co., Woodlawn, Pa.

This paper deals with various phases of refractories' use in the steel plant, such as checker brick, insulation, high-temperature cements, and tests.

Louis A. Smith

Suggestions regarding the improvements of products which are presented to the user will be discussed, such as control of warpage and size of fire brick, standardization of shapes, furnace designs, and methods by which refractories are made.

(2) Refractory Problems in Basic Alloy Steel Production

By Gilbert Soler, Manager of Research, The Timken Steel & Tube Co., Canton, Ohio

Following a discussion of the relation which should exist between the steel producer and the manufacturer of refractories in the development of refractories which meet the specialized needs of the producer, this paper will outline the various purposes for which refractories are used in a modern alloy steel plant. The relation between steel quality and refractory cost will be developed, coördinating the refractory problems with service conditions which arise in the steel plant.

Gilbert Soler

Based on his experience at The Timken Steel & Tube Co., Mr. Soler will discuss from the operator's viewpoint the refractory problems connected with both open-hearth and electric furnaces, ladles and accessories, soaking pits, reheating furnaces, heat-treating furnaces, etc.

The interpretation of the causes of refractory failures will likewise be discussed, together with methods developed at the Timken plant for testing refractories.

(3) A Discussion of the Action of Coal-Ash Slags on Fireclay Refractories

By Harold E. Simpson, Ceramic Engineer, Battelle Memorial Institute, Columbus, Ohio

The action of coal-ash slags on fireclay refractories was studied by microscopic examination of thin sections prepared from quenched samples of ash and refractory heated together. The refractories used varied as to type of clays, method of fabrication, grind, and firing treatment. The coal ashes used varied from highly corrosive to non-corrosive ashes. The temperatures at which the refractories disintegrate due to the slagging action of the coal ash are given and the formation of the various minerals discussed.

Harold E. Simpson

(4) Observations on the Behavior of Refractories in Glass Manufacture

By George V. McCauley, Corning Glass Works, Corning, N. Y.

(5) Notes on Refractories for the Electrothermic Zinc Industry.

By W. B. McBride, St. Joseph Lead Company, Josephtown, Pa.

Harold E. Simpson

Harold E. Simpson was born in Columbus, Ohio, June 16, 1903; Bachelor's Degree in Ceramic Engineering, Ohio State University, 1925; Master of Science, Ohio State University, 1926; Doctor of Philosophy, Ohio State University, 1929; Fellowship U. S. Bureau of Mines, Ohio State University in 1925–26, working on specific heats of clays; Fellowship U. S. Bureau of Standards, Ohio State University, 1926–27, working on enamel problems; Assistant Professor in Ceramic Engineering Dept., Rutgers University, New Brunswick, N. J., 1929–30, teaching glass and enamel work; Research Engineer, Battelle Memorial Institute, working on refractory and enamel problems since July, 1930.

NECROLOGY

J. M. Sanders

J. M. Sanders, Moundsville, W. Va., passed away on June 26, 1935. Mr. Sanders assisted in establishing the United States Stamping Company of Moundsville, and at the time of his death was president of this Company. He was formerly a member of the American Ceramic Society.

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EMRICH, EMERSON W., 206 Gregory Blvd., East Norwalk, Conn.; technical salesman, Ceramic Department, R. T. Vanderbilt Co., New York, N. Y.

KAISER, CARL E., 281 Deshler Ave., Columbus, Ohio; junior draftsman, U. S. Engineers, Zanesville District.

LEITTEN, CARL F., 50 Hawkins Ave., Hamburg, N. Y.; superintendent, Refractories Department, Electro Refractories and Alloys Corp.

OSTRANDER, VAN RENSSELAER, 333 Grandview Ave., Zelienople, Pa.; ceramic engineer, Lava Crucible Co. of Pittsburgh.

SOLOMON, EARL A., 211 Winslow Ave., Buffalo, N. Y.; Electro Refractories and Alloys Corp.

TUTTLE, GEORGE N., 56 North Willowgrove Ave., Dayton, Ohio; ceramic engineer, Frigidaire Corp., Plant II, Moraine City, Ohio.

WANG, HAROLD E. M., Yao Hua Mechanical Glass Co., Chinwangtao, Hopei Province, North China.

Student

MUNROE, HELEN B., University of New Hampshire.

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K. C. Lu	2	H. E. White	1
C. C. Treischel	1	Office	1
			8

Student

P. I. Woodward	1

GRAND TOTAL 10

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BAIR, GEORGE J., 201 High St., State College, Pa. (Massachusetts Institute of Technology, Cambridge, Mass.)

DERRER, CHARLES F., JR., Wheeling Tile Co., Wheeling, W. Va. (Columbus, Ohio)

DIETZEL, ADOLF, Technological Dept. of the Kaiser Wilhelm Institute for Silica Research, Faradayweg 16, Berlin-Dahlem Germany. (Karlsruhe, Germany)

GAUTSCH, MURRAY C., Metal & Thermit Corp., East Chicago, Ind. (Metal & Thermit Corp., Carteret, N. J.)

GREEN, ALLEN P., JR., A. P. Green Fire Brick Co., 50 Church St., New York, N. Y. (A. P. Green Fire Brick Co., Mexico, Mo.)

HITE, EVERETT C., Timken Steel & Tube Co., Canton, Ohio. (Pleasantville, Ohio)

KAY, WILLIAM T., A. P. Green Fire Brick Co., 50 Church St., New York, N. Y. (A. P. Green Fire Brick Co., Mexico, Mo.)

KUECHLER, ADOLPH, Sterling Grinding Wheel Co., Tiffin, Ohio. (Columbus, Ohio)

LANE, RICHARD O., Graduate School, Massachusetts Institute of Technology, Cambridge, Mass. (American Steel and Wire Co., East Haven, Conn.)

LONG, R. N., Houston, Pa. (Canonsburg Pottery Co., Canonsburg, Pa.)

LU, KAI-CHING, Yao Hua Mechanical Glass Co., Chinwangtao, Hopei Province, North China. (Kailan Mining Administration, Tongshan, N. China)

REED, HEROLD N., Tyler Sales-Fixture Co., Niles, Mich. (Willard, Ohio)

RUECKEL, W. C., Koppers Construction Co., Koppers Bldg., Pittsburgh, Pa. (Engineering Experiment Station, Ohio State University, Columbus, Ohio)

SCHOFIELD, H. ZANE, Engineering Experiment Station, Ohio State University, Columbus, Ohio. (Standard Tile Co., Zanesville, Ohio)

SEELEY, EUGENE L., Spring Lake Pottery, 1003 West St., Corning, Iowa. (Toledo, Iowa)

SHERWOOD, R. F., 282 Sherman Ave., Hamilton, Ontario, Canada. (700 Bank of Commerce Bldg.)

SMITH, EDWIN B., Owens-Illinois Glass Co., Streator, Ill. (North Carolina State College, Raleigh, N. C.)

STEVENS, JOE, 3002 Walnut, Huntington Park, Calif. (A. P. Green Fire Brick Co., Mexico, Mo.)

SWALM, PHAON H., P. O. Box 178, Kingston, Ontario, Canada. (Wheeling Tile Co., Wheeling, W. Va.)

WILLIAMS, ARTHUR E., 232 Belmont St., N.E., Warren, Ohio. (Urbana, Ill.)

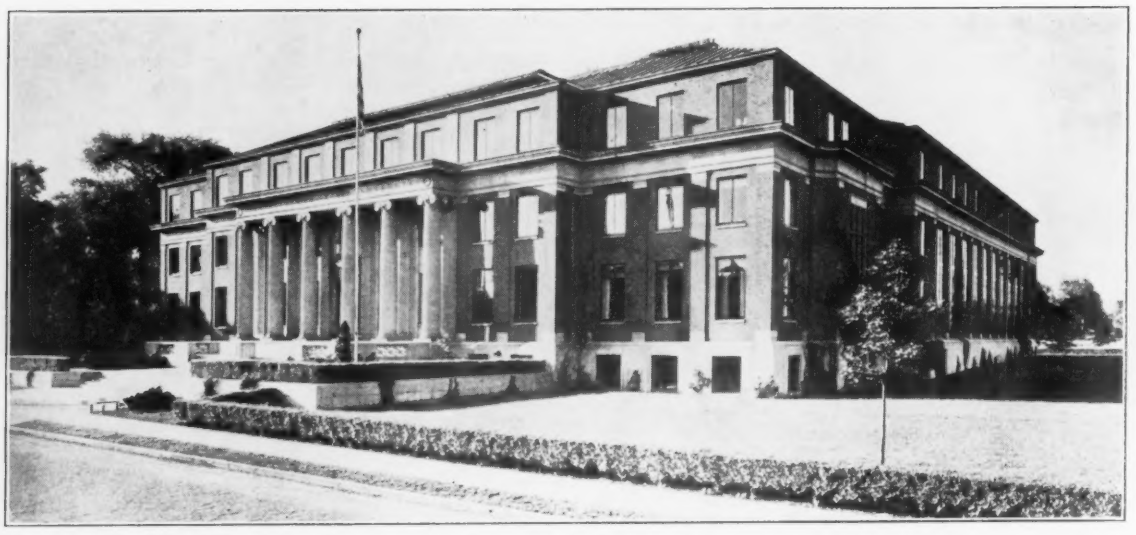
Student

HESTER, WESTON T., 401 E. Daniel St., Champaign, Ill. (Peoria, Ill.)

YOUNG, DAVID H., 219 W. Church St., Rockmont, Ga. (Atlanta, Ga.)

* Address in parentheses is the old address.

WILL YOU HAVE A PAPER READY FOR THE 1936 MEETING?



Battelle Memorial Institute, Columbus, Ohio, organized to serve industry by the practical application of science.

BATTELLE MEMORIAL INSTITUTE INVITES VISITORS DURING 1936 ANNUAL MEETING OF AMERICAN CERAMIC SOCIETY, MARCH 29–APRIL 4[1]

Thirty-Sixth Anniversary of Organized Industrial Research Commemorated Next Year at Annual Meeting, Columbus, Ohio

Battelle Memorial Institute, housed in a three-story building containing about 90,000 square feet of floor space, at 505 King Avenue, Columbus, Ohio, is one of several institutions in Columbus which have contributed to the growth of the ceramic industries.

Practical Application of Science

The Institute was endowed by the family of Gordon Battelle to serve industry by the practical application of science. To that end the Institute has engaged in original research in many fields to increase the spread of knowledge of metals, fuels, refractories, ceramics, and applied chemistry.

It is included among institutions to be visited by ceramists during the 1936 Annual Meeting of the American Ceramic Society, which is being held in Columbus, Ohio, March 29 to April 4, 1936, just thirty-six years after the establishment of the first organized industrial research laboratory in the United States (see p. 323).

Widespread Activities of Institute

The staff, which has been assembled over a period of six years, numbers at present about one hundred and twenty-five. These men have been selected on the basis of training and experience as experts in the different fields in which the Institute is interested. The widespread interests and activities of the staff contribute a wealth of experience and a broad basic viewpoint to any research problem.

[1] All meetings of the American Ceramic Society are to be held in hotels; see page 210, *The Bulletin*, June, 1935, for meeting place schedule.

Clyde E. Williams, Director, Battelle Memorial Institute, has charge of a varied research and development program in the field of ceramics and refractories.

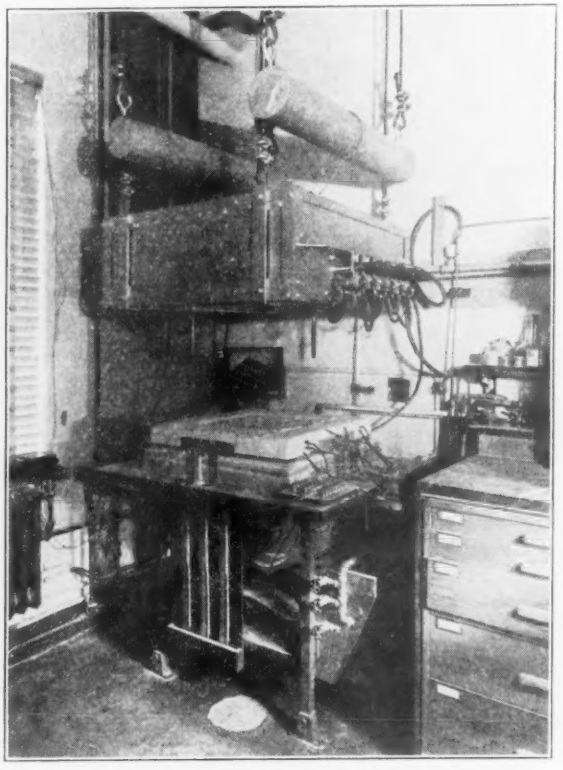
In the field of ceramics and refractories, Clyde E. Williams, Director, O. E. Harder, J. D. Sullivan, F. B. Hobart, C. R. Austin, and H. E. Simpson direct a varied research and development program. R. A. Sherman has been active in the study of different fuels and methods of firing which have close connections with the ceramic industry. H. W. Gillett, Chief Technical Advisor, and H. W. Russell

Chief Physicist, act in an advisory capacity and bring to the work the points of view of the metallurgist and physicist.

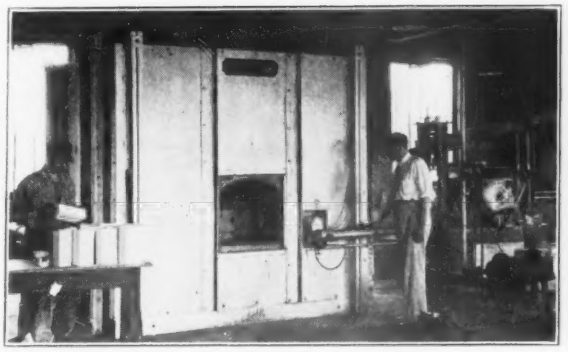
Fundamental Types of Research

The work at Battelle is planned to make definite, practical contributions to industry. As part of its service to industry, the Institute carries on under its endowment certain fundamental types of research which are of interest to large sections of industry. A series of technical papers on the properties of metals, studies of the ceramic applications of metals, the corrosion of metals, the high-temperature properties of metals, the combustion of fuels, and the slagging of refractories are examples of this type of work. The Institute maintains an extensive library and has catalogued many thousands of references which are available to interested persons.

In addition to this general type of work which is supported by the endowment, the Institute works in close coöperation with individual concerns and associations. The facilities of the Institute and the staff are available at cost to individuals or to organizations who are interested in working out specific problems.



Apparatus used for conductivity tests is shown in the above illustration.



A view of the Ceramic Laboratory is shown in this photograph.

The cost of this work, which is budgeted and a matter of contract, is borne by the sponsor, and the results, including new developments and inventions, are the sole property of the sponsor. Many organizations use this service to supplement the efforts of their technical staffs. Many worthwhile results have been obtained in the sponsored projects.

Ceramics and Refractories Research

The Institute is well equipped for research in ceramics and refractories. Mixers and mullers for the preparation of material, a 150-ton hydraulic press, humidity driers, and an experimental high duty kiln, which can be operated up to a temperature of 2900°F, are available for the manufacture of refractories. Testing equipment includes P.C.E. furnaces, which can be heated to cone 38, and apparatus for slaking tests, modified spalling tests, load-bearing tests, and the usual equipment for physical testing. Special apparatus is available for determining dielectric capacities and thermal and electrical conductivities at ordinary and at high temperatures.

Complete metallographic and physical-testing equipment is available. Apparatus for the preparation, application, and firing of enamels and the testing of enameled ware is installed.

The development of the so-called super-refractories is of immediate interest to industry and a great deal of work has been done in this field. Work is being done on high-temperature cements, magnesite refractories, insulating brick, and acoustical materials.

Work on sheet-steel enameling is being directed along the lines of attempting to correlate practice in the mills which prepare the metal and in the enameling plants which use it. Other active investigations are on the prevention of blistering in cast-iron enameling and on the enameling of copper. The development of "Crystal-cote" enamel for copper was done in this laboratory.

—V. H. Schnee

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OTTO SCHOTT*

Otto Schott, Jena, Germany, one of the four Honorary Members of the American Ceramic Society, died August 27, 1935, according to word received from H. Maurach of the Deutsche Glastechnische Gesellschaft E. V., Frankfurt (Main), Germany.

Dr. Schott, dean of glass technologists, was 85 at the time of his death. His work, started with Ernst Abbe and later continued independently, began a new epoch in glassmaking.

"He was the first to leave the ways of crude empiricism, and by his systematic researches created a science of glass which enabled him to impress on glass whatever qualities the circumstances required. He founded the Jena Glassworks Schott & Gen. with this aim and extended it to its present-day size."[1]

Dr. Otto Schott

Academic Training

Dr. Schott studied in the Technical College at Aachen, then at the Universities of Würzburg and Leipzig. In the Laboratory of Agricultural Chemistry, Leipzig, he conducted researches on a subject of his own selection. The results were submitted for his Doctorate in Jena under the title, "Defects in the Manufacture of Window Glass." He was graduated there in 1875.

In the holidays he worked as a volunteer in a chemical factory near Hagen and was engaged there after his graduation. An extensive work of his on toughened glass was awarded a prize by the Industrial Institute of Berlin.

His works on optical glasses containing lithium first brought him in contact with Ernst Abbe, May 27, 1879. At Abbe's suggestion he moved to Jena in 1882.

Chemistry of Fiery Fluxes

Schott's chief work was first done in the borderland of mineral technology, his aim being a comprehensive chemistry of fiery fluxes, of which the production of glasses forms a part. In 1881, Schott published contributions to the knowledge of inorganic melting compounds. He first turned his attention to optical properties and applications when the production of lithium glass seemed to offer new possibilities.

After important preliminary work and supported by the results of numerous trial melts, Schott and Abbe in 1882 set up a laboratory of technical glass.

Many promising types of glass for optics and also of borosilicate glasses for thermometers were produced.

Formation of Famous Company

In January, 1884, four partners, Schott, Abbe, and Zeiss, father and son, formed the firm of "Schott and Genossen Laboratory of Technical Glass." This was later supported by generous contributions from the Prussian Diet.

Optical glasses, thermometer tubes, chemical glasses for laboratory use, and heat-resisting glass cylinders for incandescent gas lighting were soon in production. Tubes for different purposes, glasses for electrical work, and so forth, were added later.

The partnership deed stipulated that at Schott's death the works should be left to the Carl Zeiss Institute. In 1919, Schott's share of the Works was given to the Institute and eight years later he retired from direction of the business.

The Otto Schott Medal of the German Society of Glass Technology, an award for eminent services in glass research, was founded in Dr. Schott's honor.

In his lifetime he was recipient of many high honors and distinguished titles from scientific and technological societies.

* Material is included by E. Berger, "Dr Otto Schott's Eightieth Birthday," *Jour. Soc. Glass Tech.* **15**, 99–101*P* (1931).

[1] From tribute to Dr. Schott when elected first honorary member of the German Society of Glass Technology.

NOTES AND NEWS FOR CERAMISTS

GRAPHICAL "DICTIONARY" OF DRAWINGS ADOPTED AS STANDARD

Thirty national organizations and a number of independent experts have developed a graphical "dictionary" of drawings. The work has been adopted by the American Standards Association and will be used as a guide throughout the country.

Heretofore, a lack of uniformity in symbols and other practice existed. Drawings made by one company were not intelligible to other concerns.

Most of the larger drafting rooms devised their own standard practices, and graphical symbols in unnecessary variety have been developed. This new standard seeks to eliminate this confusion.

Instructors in schools and colleges, because of this confusion, have been at loss to know what practice to teach in their mechanical-drawing and machine-shop classes.

Questionnaires returned from 900 organizations were codified and used as the basis of the first draft of the standard.

The Society for Promotion of Engineering Education and the American Society of Mechanical Engineers took the leadership in the work and were sponsors of the project.

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Ceramic Headquarters For 1936

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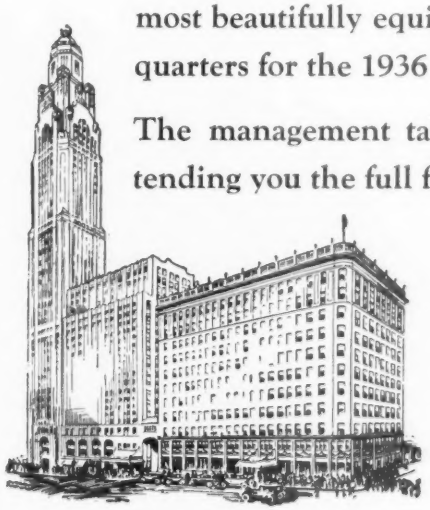

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The Vitro Mfg. Co.

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The Exolon Co.
The Hommel Co., O., Inc.
Norton Co.
The Vitro Mfg. Co.

Alundum (Refractory Products)
Norton Co.

Ammonium Bicarbonate
Solvay Sales Corp.

Ammonium Bifluoride
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The Hommel Co., O., Inc.
Jungmann & Co., Inc.
The Roessler & Hasslacher Chemical Co.
The Vitro Mfg. Co.

Ammonium Carbonate
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Drakenfeld & Co., B. F.
The Hommel Co., O., Inc.
The Roessler & Hasslacher Chemical Co.

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The Roessler & Hasslacher Chemical Co.
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Ball Mills
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The Hommel Co., O., Inc.
McDanel Refractory Porcelain Co.
The Vitro Mfg. Co.

Ball Mills (Laboratory Type)
Ceramic Color & Chemical Mfg. Co.
Chicago Vitreous Enamel Product Co.
Denver Fire Clay Co.
The Hommel Co., O., Inc.
The Vitro Mfg. Co.

Barium Carbonate
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Hammill & Gillespie, Inc.
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The Vitro Mfg. Co.

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Blocks (Refractory)
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Chicago Vitreous Enamel Product Co.
Denver Fire Clay Co.
Norton Co.
Pittsburgh Plate Glass Co.
The Vitro Mfg. Co.

Borax
American Potash & Chemical Co.
Denver Fire Clay Co.
Drakenfeld & Co., B. F.
The Hommel Co., O., Inc.
Pacific Coast Borax Co.
The Roessler & Hasslacher Chemical Co.
The Vitro Mfg. Co.

Borax Glass
American Potash and Chemical Corp.
Ceramic Color & Chemical Mfg. Co.
Denver Fire Clay Co.
Drakenfeld & Co., B. F.
The Hommel Co., O., Inc.
Pacific Coast Borax Co.
The Roessler & Hasslacher Chemical Co.
The Vitro Mfg. Co.

Boric Acid (Anhydrous)
Denver Fire Clay Co.
Drakenfeld & Co., B. F.
The Hommel Co., O., Inc.
Pacific Coast Borax Co.
The Vitro Mfg. Co.

Boric Acid (Crystal, Granular, or Powder)
American Potash & Chemical Corp.
Ceramic Color & Chemical Mfg. Co.
Denver Fire Clay Co.
Drakenfeld & Co., B. F.
The Hommel Co., O., Inc.
Pacific Coast Borax Co.
The Roessler & Hasslacher Chemical Co.
The Vitro Mfg. Co.

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Brick (Refractory)
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The Vitro Mfg. Co.

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Solvay Sales Corp.
The Vitro Mfg. Co.

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Metal & Thermit Corp.
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The Roessler & Hasslacher Chemical Co.
The Vitro Mfg. Co.

Clay (Ball)
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The Hommel Co., O., Inc.
Kentucky-Tennessee Clay Co.
Paper Makers Importing Co.
Potters Supply Co.
The Roessler & Hasslacher Chemical Co.
Spinks Clay Co., H. C.
The Vitro Mfg. Co.

Clay (China)
Ceramic Color & Chemical Mfg. Co.
Consolidated Feldspar Corp.
Edgar Brothers Co.
Hammill & Gillespie, Inc.
The Hommel Co., O., Inc.
Paper Makers Importing Co.
The Roessler & Hasslacher Chemical Co.
The Vitro Mfg. Co.

Clay (Electrical, Porcelain)
Ceramic Color & Chemical Mfg. Co.
Edgar Brothers Co.
Hammill & Gillespie, Inc.
Kentucky-Tennessee Clay Co.
Spinks Clay Co., H. C.

Clay (Enamel)
Ceramic Color & Chemical Mfg. Co.
Chicago Vitreous Enamel Product Co.
Edgar Brothers Co.
Ferro Enamel Corp.
Hammill & Gillespie, Inc.
The Hommel Co., O., Inc.
Kentucky-Tennessee Clay Co.
Metal & Thermit Corp.
Paper Makers Importing Co.
Porcelain Enamel & Mfg. Co.
The Roessler & Hasslacher Chemical Co.
Spinks Clay Co., H. C.
Titanium Alloy Mfg. Co.
The Vitro Mfg. Co.

Clay (Fire)
Chicago Vitreous Enamel Product Co.
Denver Fire Clay Co.
Edgar Brothers Co.
Kentucky-Tennessee Clay Co.
Paper Makers Importing Co.
Pittsburgh Plate Glass Co.
Potters Supply Co.

Clay (German Vallendar)
Ceramic Color & Chemical Mfg. Co.
Chicago Vitreous Enamel Product Co.
Ferro Enamel Corp.
Hammill & Gillespie, Inc.
The Hommel Co., O., Inc.
Jungmann & Co., Inc.
Porcelain Enamel & Mfg. Co.
The Roessler & Hasslacher Chemical Co.
The Vitro Mfg. Co.

Clay Miners
Edgar Brothers Co.
Kentucky-Tennessee Clay Co.
Paper Makers Importing Co.
Spinks Clay Co., H. C.

Clay (Potters)
Denver Fire Clay Co.
Hammill & Gillespie, Inc.
The Hommel Co., O., Inc.
Paper Makers Importing Co.
Spinks Clay Co., H. C.

Clay (Process Equipment)
Bonnot Co.

Clay (Sagger)
Edgar Brothers Co.
The Hommel Co., O., Inc.
Kentucky-Tennessee Clay Co.
Paper Makers Importing Co.
Pittsburgh Plate Glass Co.
Potters Supply Co.
Spinks Clay Co., H. C.

Clay (Wad)
Kentucky-Tennessee Clay Co.
Potters Supply Co.
Spinks Clay Co., H. C.

Clay (Wall Tile)
Hammill & Gillespie, Inc.
Kentucky-Tennessee Clay Co.
Paper Makers Importing Co
Spinks Clay Co., H. C.

Clocks (Gauge Board)
Chicago Vitreous Enamel Product Co.
Ferro Enamel Corp.
The Hommel Co., O., Inc.

Cobalt Oxide
Ceramic Color & Chemical Mfg. Co.
Drakenfeld & Co., B. F.
Ferro Enamel Corp.
The Hommel Co., O., Inc.
Jungmann & Co., Inc.
The Roessler & Hasslacher Chemical Co.
The Vitro Mfg. Co.

Colors
Ceramic Color & Chemical Mfg. Co.
Chicago Vitreous Enamel Product Co.
Drakenfeld & Co., B. F.
Ferro Enamel Corp.
The Hommel Co., O., Inc.
Pittsburgh Plate Glass Co.
The Roessler & Hasslacher Chemical Co.
The Vitro Mfg. Co.

Cones
The Edward Orton, Jr., Ceramic Foundation

Conveying Equipment
Simplex Eng. Co.
Simpson Foundry & Eng. Co.

Cornwall Stone (Imported)
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Drakenfeld & Co., B. F.
Hammill & Gillespie, Inc.
The Hommel Co., O., Inc.
Paper Makers Importing Co.
The Roessler & Hasslacher Chemical Co.

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Norton Co.
Pittsburgh Plate Glass Co.
Potters Supply Co.

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Norton Co.

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Simplex Eng. Co.
Simpson Foundry & Eng. Co.

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Ceramic Color & Chemical Mfg. Co.
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Drakenfeld & Co., B. F.
The Hommel Co., O., Inc.
Pittsburgh Plate Glass Co.
The Roessler & Hasslacher Chemical Co.
The Vitro Mfg. Co.

Drying Machinery
Ferro Enamel Corp.

Enameling Equipment (Complete)
Ceramic Color & Chemical Mfg. Co.
Chicago Vitreous Enamel Product Co.
Ferro Enamel Corp.
The Hommel Co., O., Inc.
Porcelain Enamel & Mfg. Co.

Enameling Furnaces
Carborundum Co. (*Carboradiant*)
Ceramic Color & Chemical Mfg. Co.
Chicago Vitreous Enamel Product Co.
Ferro Enamel Corp.
The Hommel Co., O., Inc.
Norton Co.
Porcelain Enamel & Mfg. Co.

Enameling Iron (Sheet)
American Rolling Mill Co.

Enameling Muffles
Carborundum Co. (*Carbofrax*)
Chicago Vitreous Enamel Product Co.
Ferro Enamel Corp.
Norton Co. (*Alundum*)
Pittsburgh Plate Glass Co.

Enameling (Practical Service)
Ceramic Color & Chemical Mfg. Co.
Chicago Vitreous Enamel Product Co.
Ferro Enamel Corp.
The Hommel Co., O., Inc.
Metal & Thermit Corp.
Porcelain Enamel & Mfg. Co.
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Enamels
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Metal & Thermit Corp.
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Titanium Alloy Mfg. Co.
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Ferro Enamel Corp.

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Titanium Alloy Mfg. Co.
The Vitro Mfg. Co.

Titanium Oxide
Ceramic Color & Chemical Mfg. Co.
Drakenfeld & Co., B. F.
The Hommel Co., O., Inc.
The Roessler & Hasslacher Chemical Co.
Titanium Alloy Mfg. Co.
The Vitro Mfg. Co.

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McDanel Refractory Porcelain Co.
Norton Co.

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Whiting
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Drakenfeld & Co., B. F.
Hammill & Gillespie, Inc.
The Hommel Co., O., Inc.
Paper Makers Importing Co.
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Cobalt Oxide, Black
Cobalt Sulphate
Copper Oxides
Iron Oxides
Kryolith
Lead Chromate
Magnesium Carbonate
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Nickel Oxide, Black
Nickel Oxide, Gray
Nickel Sulphate
Potassium Bichromate
Potassium Nitrate
Powder Blue
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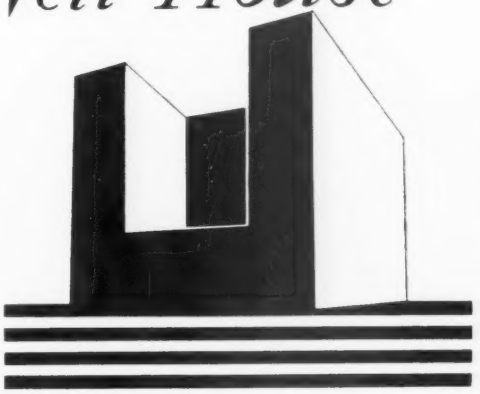

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Headquarters

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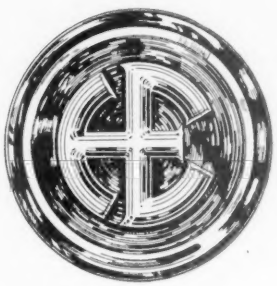

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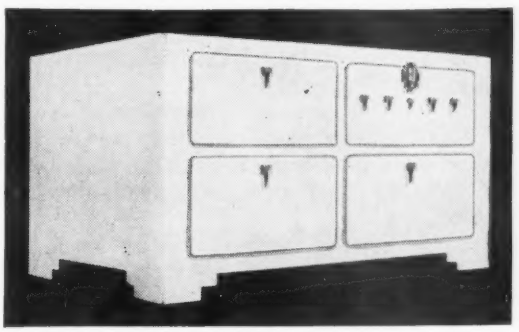

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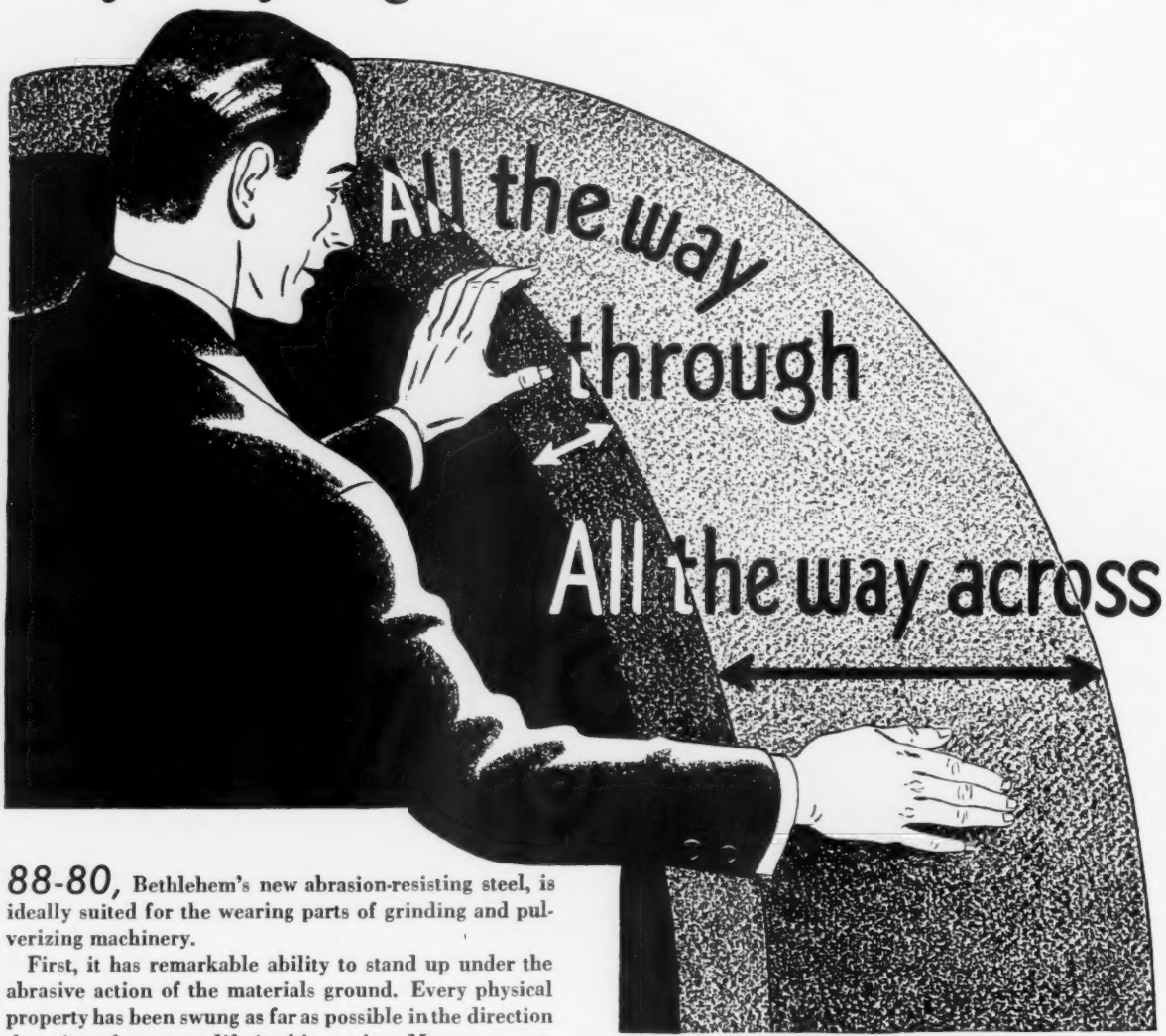

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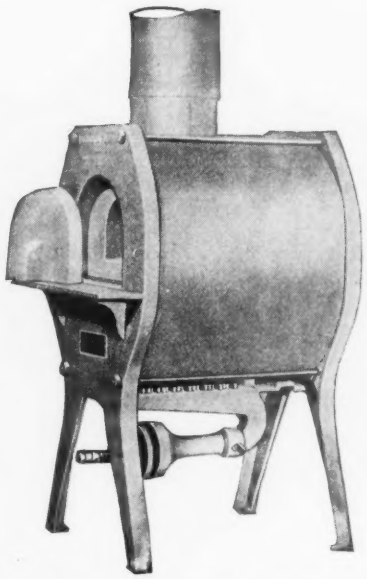

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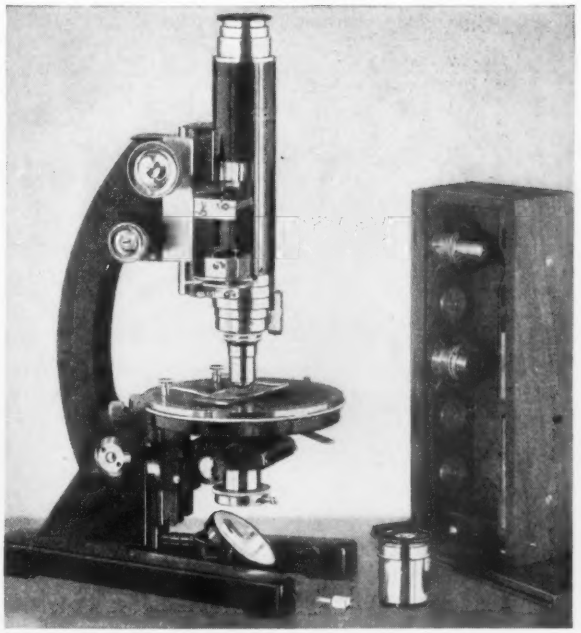

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